HICUM/L2 - Productization and Release Update

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http://www.iee.et.tu-dresden.de/iee/eb/hic_new/hic_start.html

Atmel, Heilbronn (Germany)
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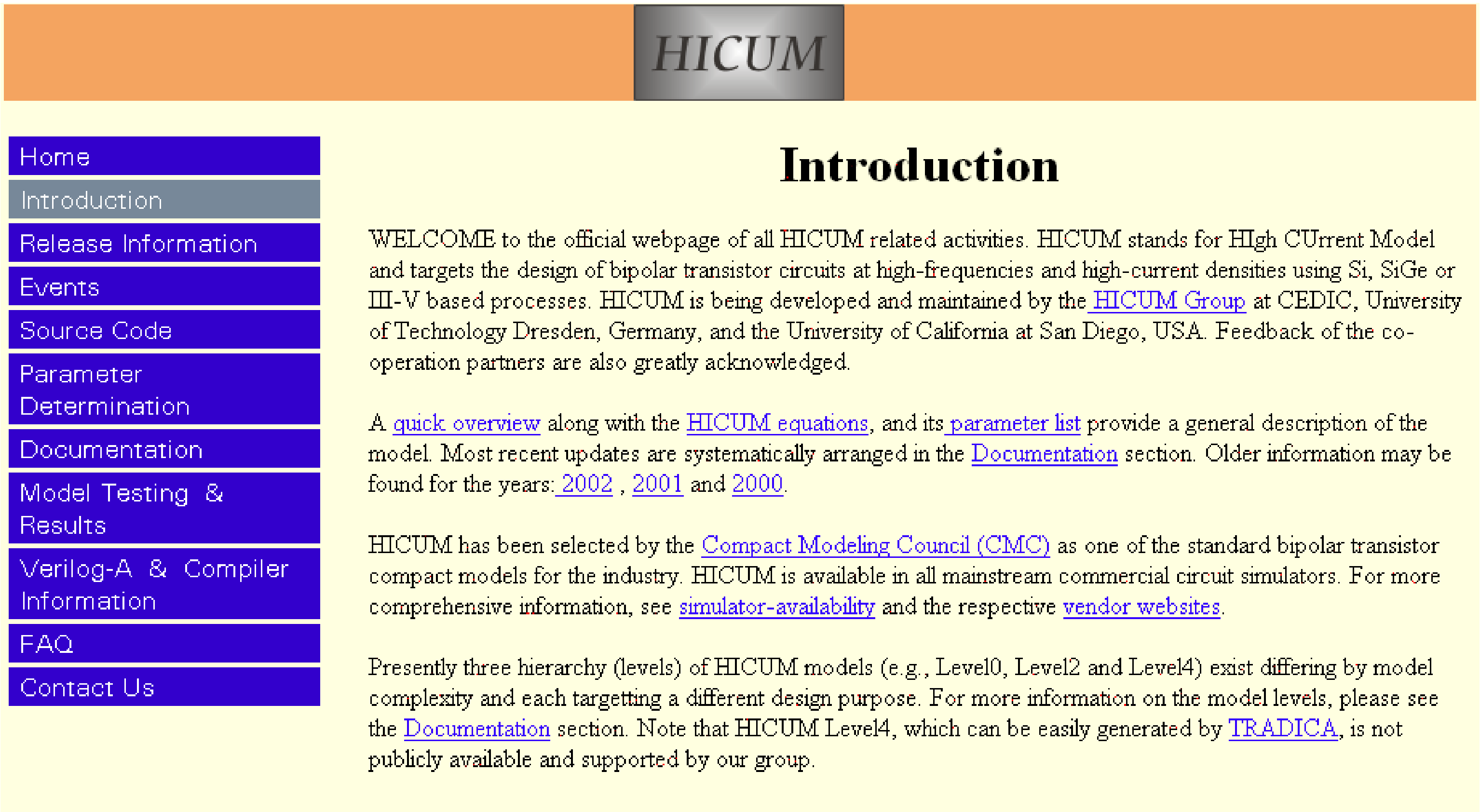
Overview

- new web-site (improved organisation of model related information)
- HICUM/Level2 Version 2.2 release
- documentation
- code/implementation related activities

Web site

new HICUM home page



HICUM

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Introduction
Release Information
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Source Code
Parameter Determination
Documentation
Model Testing & Results
Verilog-A & Compiler Information
FAQ
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Introduction

WELCOME to the official webpage of all HICUM related activities. HICUM stands for HIgh CUrrent Model and targets the design of bipolar transistor circuits at high-frequencies and high-current densities using Si, SiGe or III-V based processes. HICUM is being developed and maintained by the HICUM Group at CEDIC, University of Technology Dresden, Germany, and the University of California at San Diego, USA. Feedback of the co-operation partners are also greatly acknowledged.

A quick overview along with the HICUM equations, and its parameter list provide a general description of the model. Most recent updates are systematically arranged in the Documentation section. Older information may be found for the years: 2002 , 2001 and 2000.

HICUM has been selected by the Compact Modeling Council (CMC) as one of the standard bipolar transistor compact models for the industry. HICUM is available in all mainstream commercial circuit simulators. For more comprehensive information, see simulator-availability and the respective vendor websites.

Presently three hierarchy (levels) of HICUM models (e.g., Level0, Level2 and Level4) exist differing by model complexity and each targetting a different design purpose. For more information on the model levels, please see the Documentation section. Note that HICUM Level4, which can be easily generated by TRADICA, is not publicly available and supported by our group.

HICUM/L2 version 2.2 release

action items

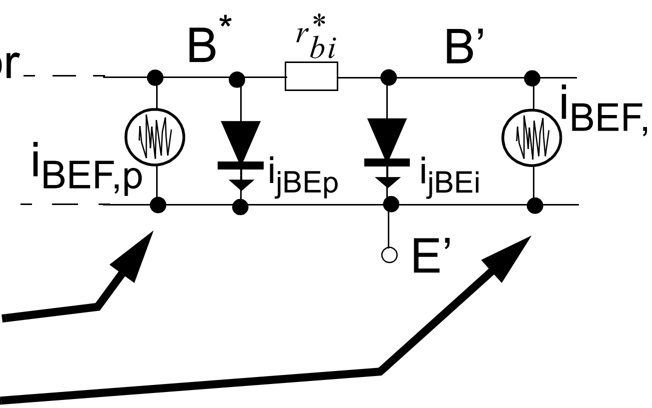
- allow variable self heating model via flag FLSH
- provide flexible flicker noise model
- version control mechanism
- focus on v2.2 instead of v2.1
  - demonstrate equivalence of v2.2 with v2.1 if default values of additional v2.2 parameters are set to those of v2.1
- complete release document for v2.2 => website
- can runtime comparisons be obtained for hand-coded vs. compiled model?
  - we do not have equivalent versions (and do not know vendor implementations)
  - may be possible once v2.2 is available in commercial simulators
- demonstration that Level0 parameters be automatically generated from level2 parameters (for interested L0 users)

Version 2.21 features

- Self-heating (SH) calculation: flag FLSH with allowed values 0, 1, 2

FLSH	meaning
0	no self-heating calculation
1	self-heating with IT and IAVL only
2	self-heating with all terms

- Flicker noise implementation with flag CFBE
  - noise source can be connected to internal (bi,ei) or perimeter (bp,ei) base node



CFBE	meaning
-2	noise source at peripheral node
-1	noise source at internal node = v2.1

- future option: CFBE can be used as correlation factor [0,1]

Version 2.21 features (cont'd)

- version control
  - version number as real valued parameter
  - each release is saved on web-site along with its documentation
    => release history available

v2.21

minor bug fixes

major fixes

new equations

- focus on completing v2.2 (Verilog) instead of v2.1
  - goal: v2.2 with existing v2.1 parameter libraries produces the same results as v2.1
  - issue: model equations can make versions incompatible for same parameter set
  - identified seven incompatible equations, all related to temperature dependence
  - relevant equations, fixes and characteristics shown below
  - v2.1 parameter set used with new v2.2 parameters set to default values

- release of V2.21 Verilog-AMS code in November 05 (see new website)

Version 2.2 vs. Version 2.1

relevant model equations

- BE injection related saturation currents

v2.1: $$I_{BEi(p)S}(T) = I_{BEi(p)S}(T_0)\left(\frac{T}{T_0}\right)^3 \exp\left[\frac{m_{cf}V_{gB}}{m_{BEi(p)}V_T}\left(\frac{T}{T_0}-1\right)-\alpha_B\Delta T\right]$$

v2.21: $$I_{BEi(p)S}(T) = I_{BEi(p)S}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BET}} \exp\left[\frac{V_{gEeff}(0)}{V_T}\left(\frac{T}{T_0}-1\right)\right]$$

- BE recombination related saturation currents

v2.1: $$I_{REi(p)S}(T) = I_{REi(p)S}(T_0)\left(\frac{T}{T_0}\right)^3 \exp\left[\frac{m_{cf}V_{gB}}{m_{REi(p)}V_T}\left(\frac{T}{T_0}-1\right)-\alpha_B\Delta T\right]$$

v2.21: $$I_{REi(p)S}(T) = I_{REi(p)S}(T_0)\left(\frac{T}{T_0}\right)^{m_g/2} \exp\left[\frac{V_{gBEeff}(0)}{2V_T}\left(\frac{T}{T_0}-1\right)\right]$$

Version 2.2 vs. Version 2.1 (cont'd)

relevant model equations

- equilibrium hole charge

v2.1: $$Q_{p0}(T) = Q_{p0}(T_0)\left[1 + \frac{z_{Ei}}{2}\left(1 - \frac{V_{DEi}(T)}{V_{DEi}(T_0)}\right)\right]$$

v2.21: $$Q_{p0}(T) = Q_{p0}(T_0)\left[2 - \left(\frac{V_{DEi}(T)}{V_{DEi}(T_0)}\right)^{z_{Ei}}\right]$$

- emitter transit time

v2.1: $$\tau_{Ef0}(T) = \tau_{Ef0}(T_0)\left(\frac{T}{T_0}\right)\frac{1}{\dfrac{a + \sqrt{a^2 + 0.01}}{2}}$$ with $a = 1 + \alpha_B \Delta T$

v2.21:

$$\tau_{Ef0}(T) = \tau_{Ef0}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{\tau Ef}} \exp\left[-\frac{\Delta V_{gBEeff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$ with $\zeta_{\tau Ef} = \zeta_{BET} - \zeta_{CT} - 0.5$

Version 2.22 vs. Version 2.1 & v2.21

relevant model equations

- BC saturation currents

v2.1 and v2.21: $$I_{BCi(x)S}(T) = I_{BCi(x)S}(T_0)\left(\frac{T}{T_0}\right)^{3}\exp\left[\frac{V_{gB}}{m_{BCi(x)}V_T}\left(\frac{T}{T_0}-1\right)\right]$$

v2.22: $$I_{BCi(x)S}(T) = I_{BCi(p)S}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BCi(xt)}}\exp\left[\frac{V_{gCeff}}{V_T}\left(\frac{T}{T_0}-1\right)\right]$$

- Substrate transistor transfer and SC saturation currents

v2.1 and v2.21: $$I_{TS(SC)S}(T) = I_{TS(SC)S}(T_0)\left(\frac{T}{T_0}\right)^{3}\exp\left[\frac{V_{gB}}{m_{Sf(c)}V_T}\left(\frac{T}{T_0}-1\right)\right]$$

v2.22: $$I_{TS(SC)S}(T) = I_{TS(SC)S}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{SCt}}\exp\left[\frac{V_{gC(S)}}{V_T}\left(\frac{T}{T_0}-1\right)\right]$$

Version 2.22 vs. Version 2.1 & v2.21 (cont'd)

relevant model equations

- Voltage separating ohmic and saturation velocity regime

v2.1 and v2.21: $$V_{lim}(T) = V_{lim}(T_0)(1 - \alpha_{vs}\Delta T)\left(\frac{T}{T_0}\right)^{\zeta_{Ci}}$$

v2.22: $$V_{lim}(T) = V_{lim}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{Ci} - \alpha_{vs}T_0}$$

- version 2.21 compatibility results available on web since Nov '05
- additional features of version 2.22
  - further code-improvement (a bug-fix in lateral current spreading)
  - code rearranged to keep compatibility with model compilers
  - thermal node as external (planned, problem in testing)
  - completely compatible with v2.1 (i.e. also in extreme operating conditions)
- version 2.22 is presently under test (to be released soon)

Version 2.22 (& 2.21) vs. Version 2.1

solution for maintaining compatibility (w/o new extraction)

- introduction of a compatibility flag FLCOMP in the parameter list:

```
if(flcomp==2.1 || flcomp==0)
   {Version 2.1 equations}
else
   {Version 2.2 equations}
```

=> default compatible with v2.1

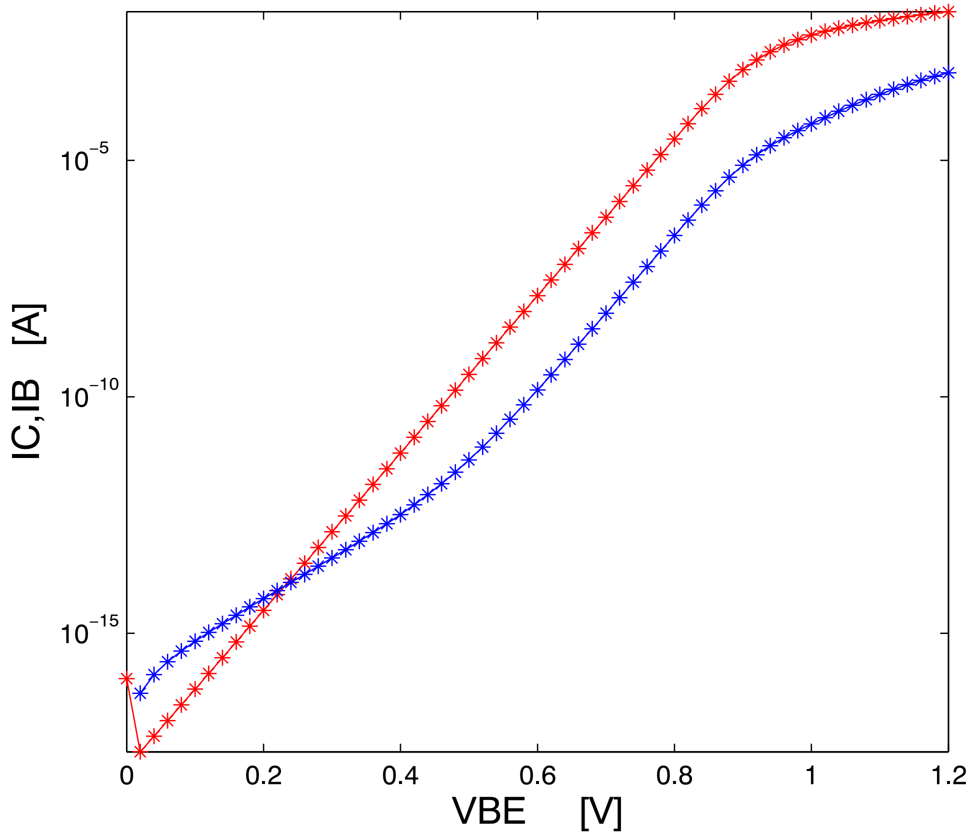
- v2.1 model parameter names
  - are still valid (transition phase? duration?)
  - will be marked "obsolete" in documentation (and also in simulator log files?)

- comparison of relevant characteristics
  - room temperature as base line
  - temperature dependence

Version 2.22 vs. Version 2.1 : quantitative results

comparison at T = 300K: Gummel plot

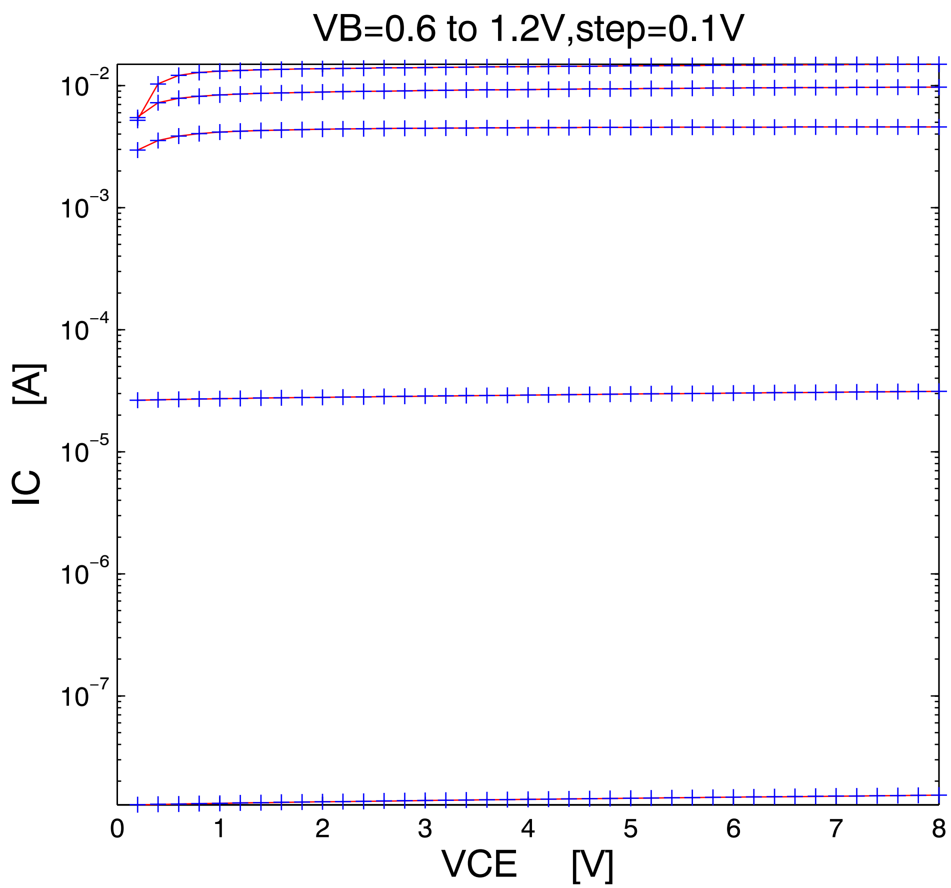
vce=2.5 V, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: forced-VBE output characteristics

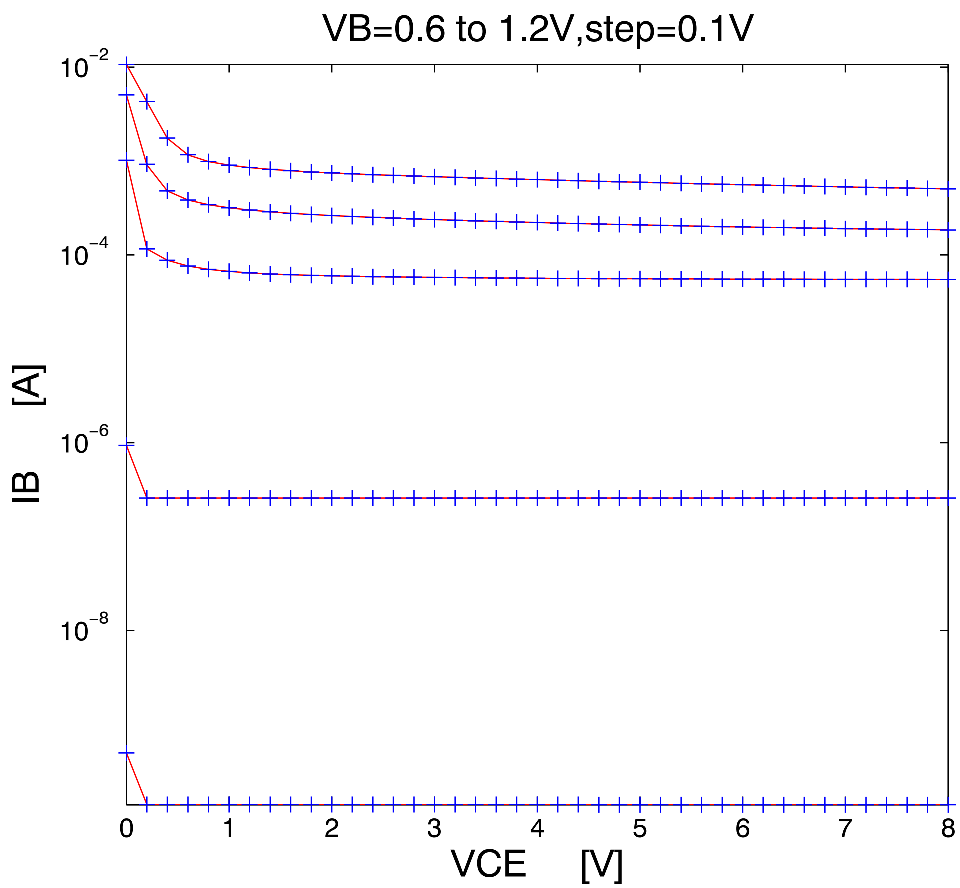
Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: IB-VCE characteristics

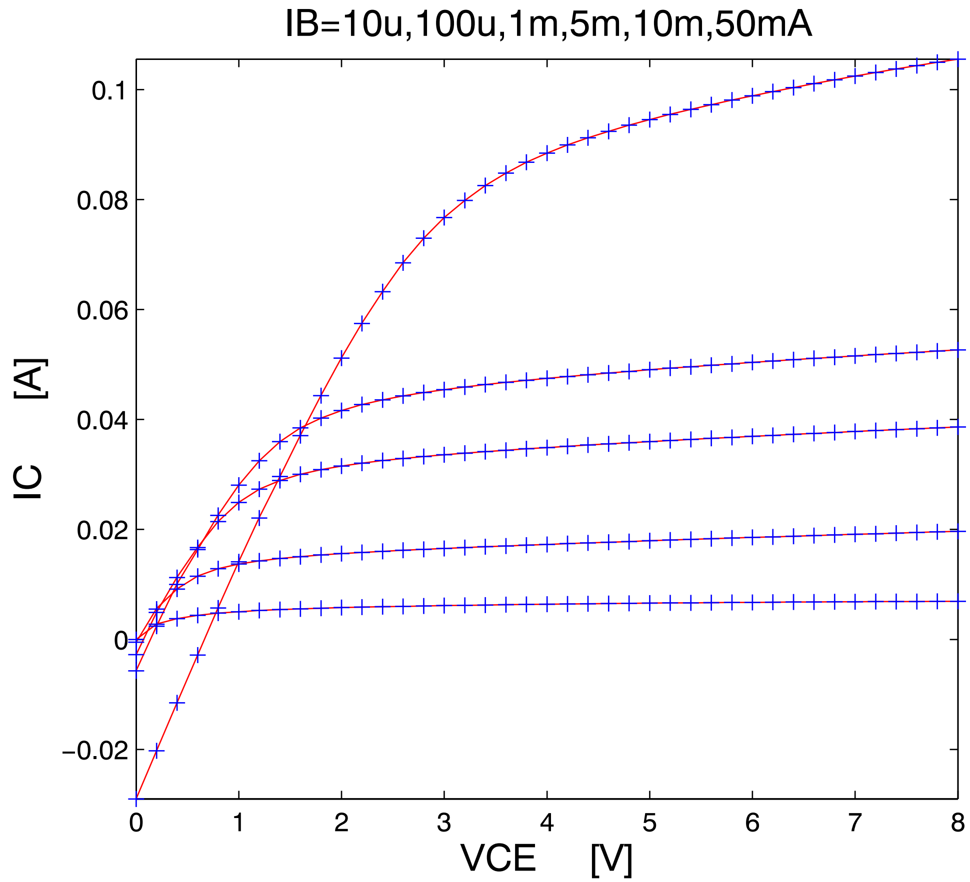
Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: forced-IB output characteristics

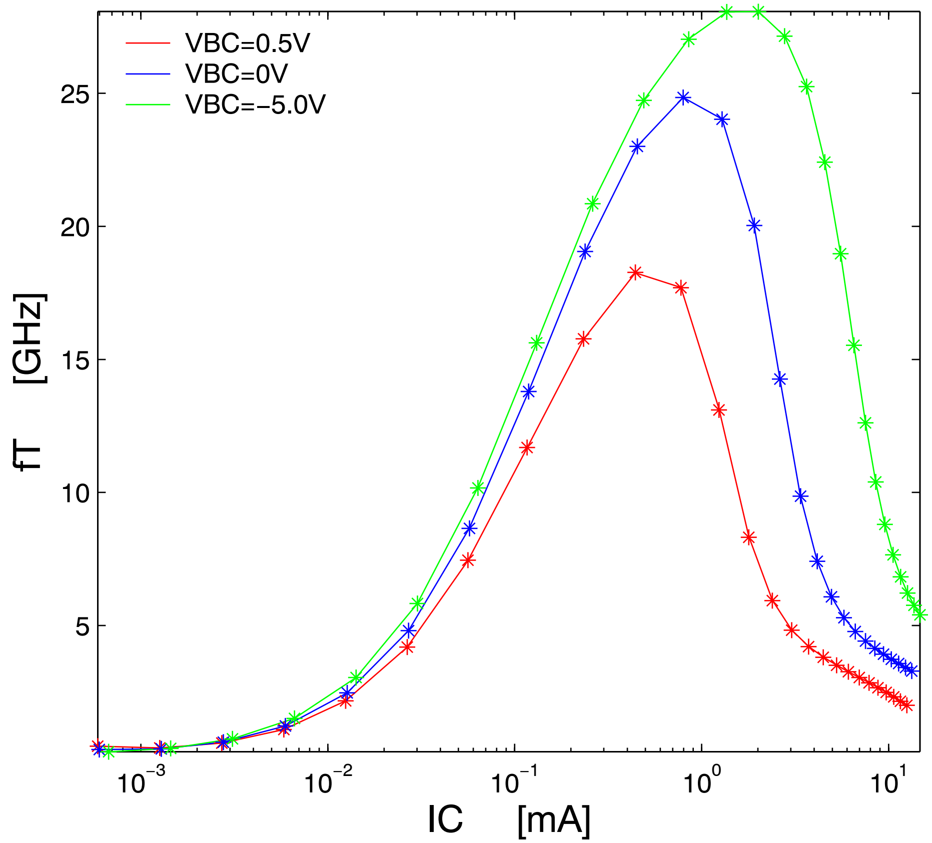
Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: transit frequency (@ 0.5GHz)

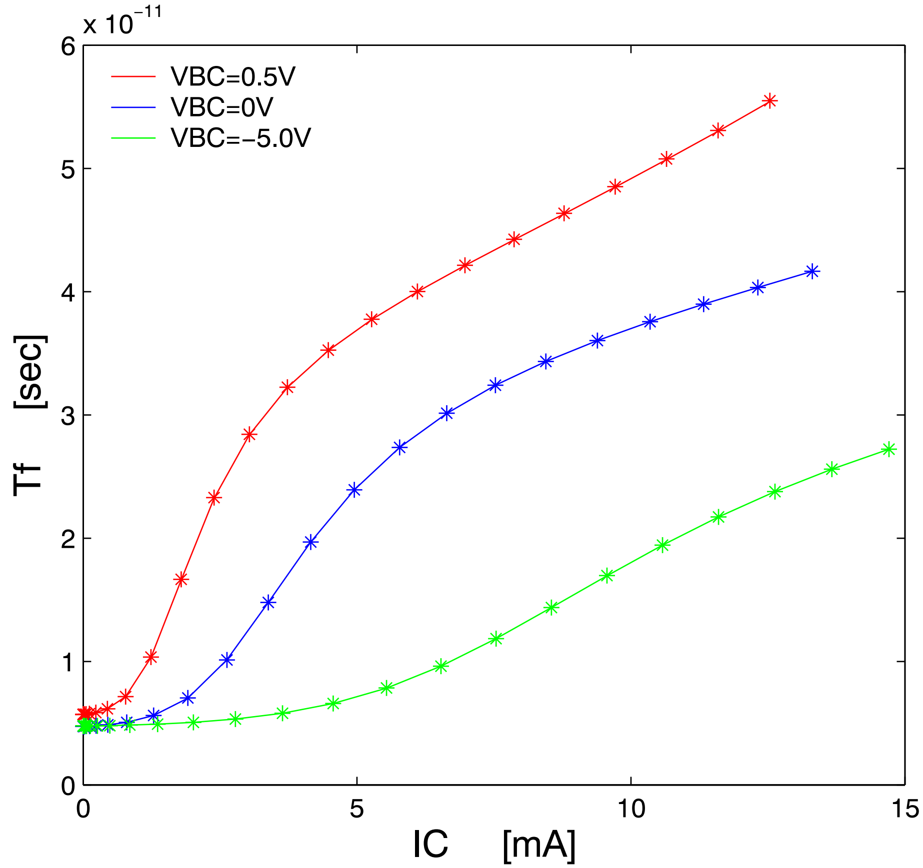
Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: transit time

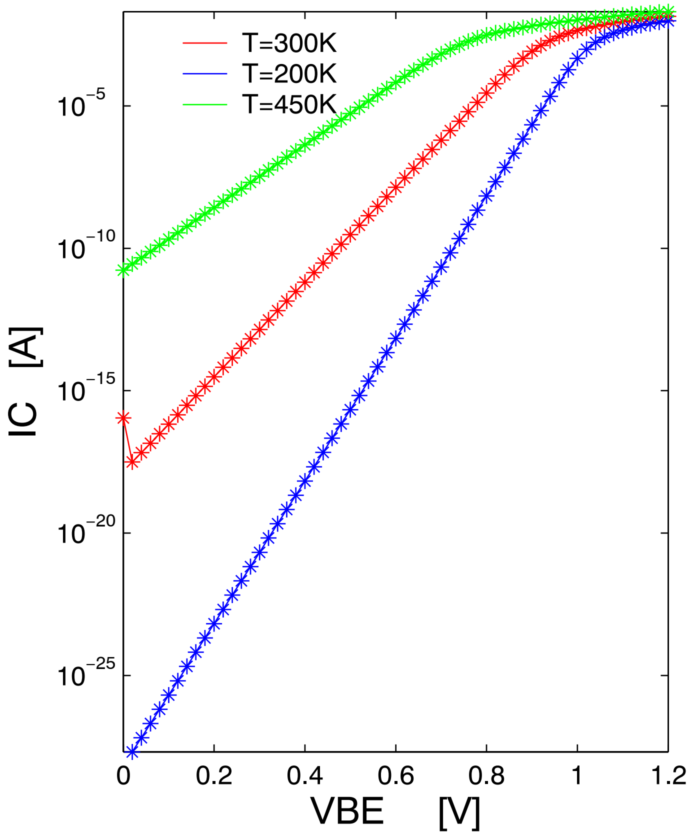
Version 2.2: continuous line, Version 2.1: symbols

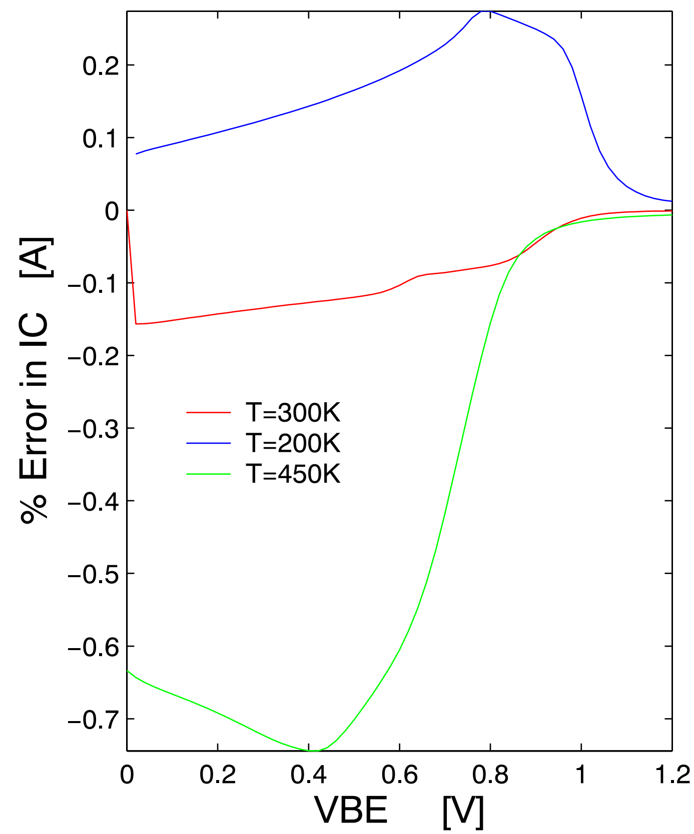


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: collector currents

vce=2.5 V, Version 2.2: continuous line, Version 2.1: symbols

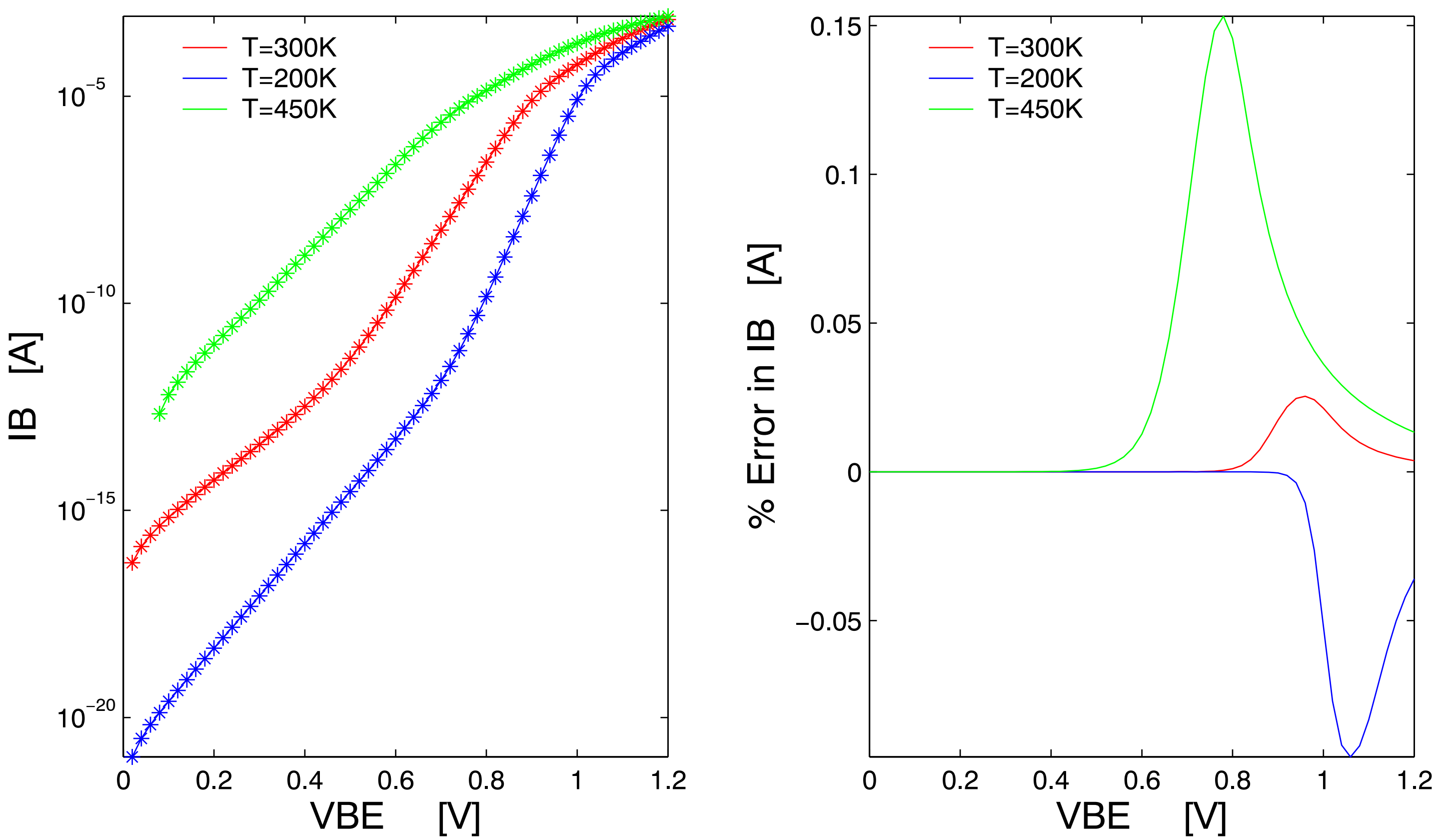




Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: base current

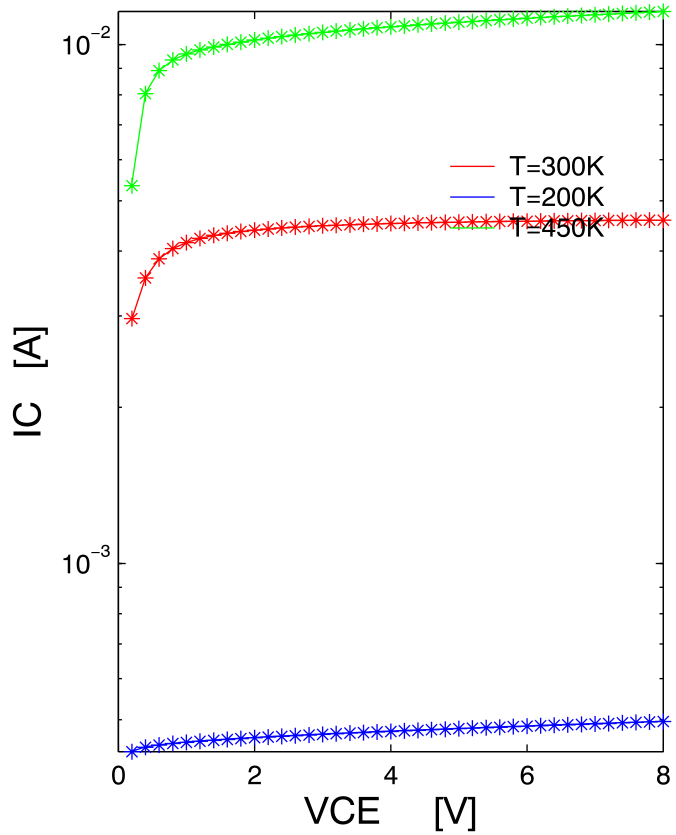
vce=2.5 V, Version 2.2: continuous line, Version 2.1: symbols

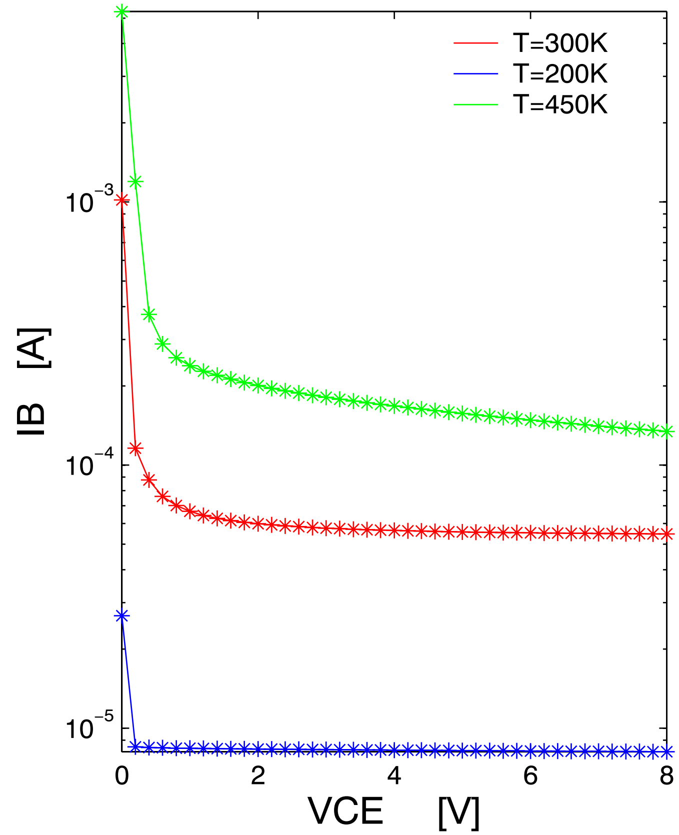


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: forced-VBE output characteristics

VBE = 1V; Version 2.2: continuous line, Version 2.1: symbols

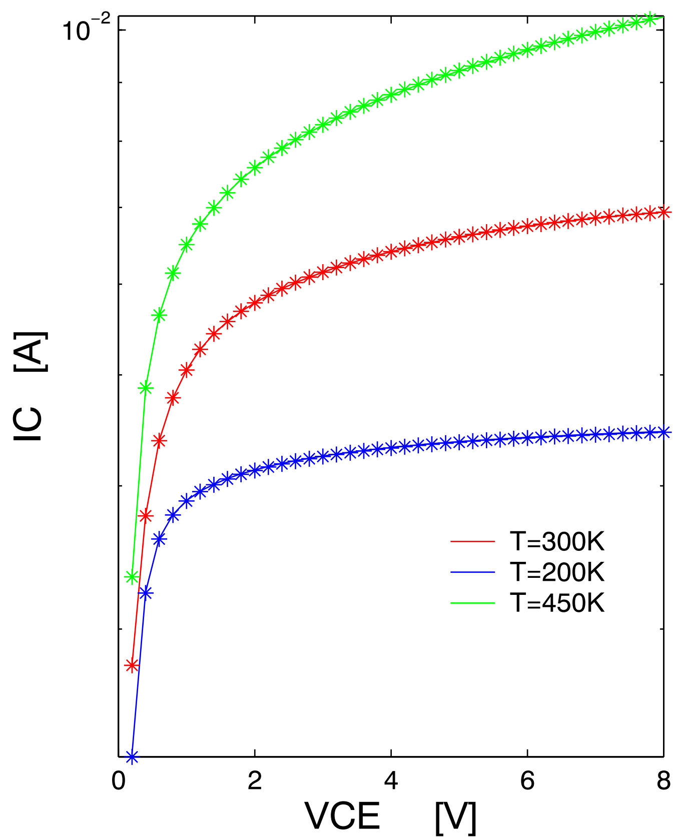


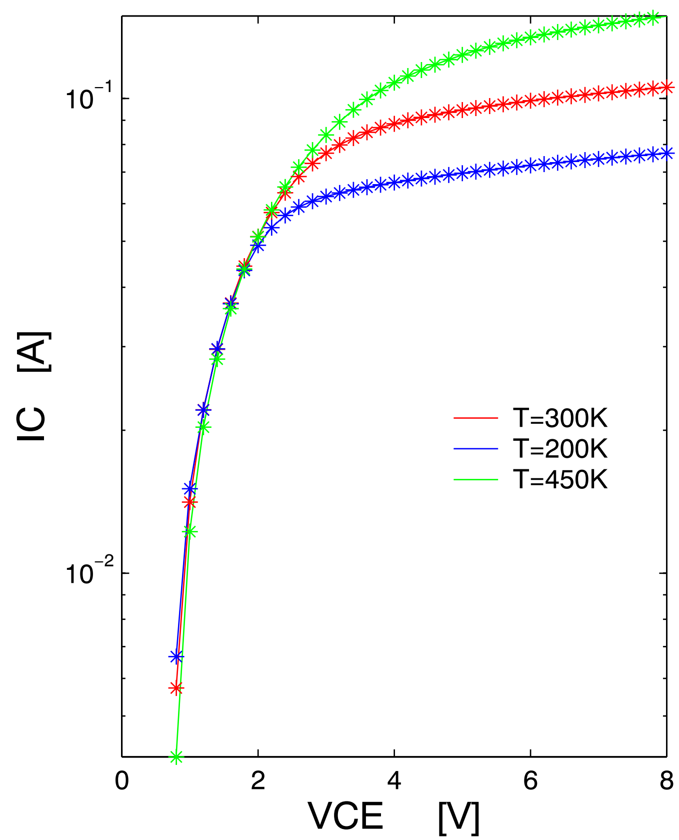


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: forced-IB output characteristics

IB=100uA & 50mA, Version 2.2: continuous line, Version 2.1: symbols

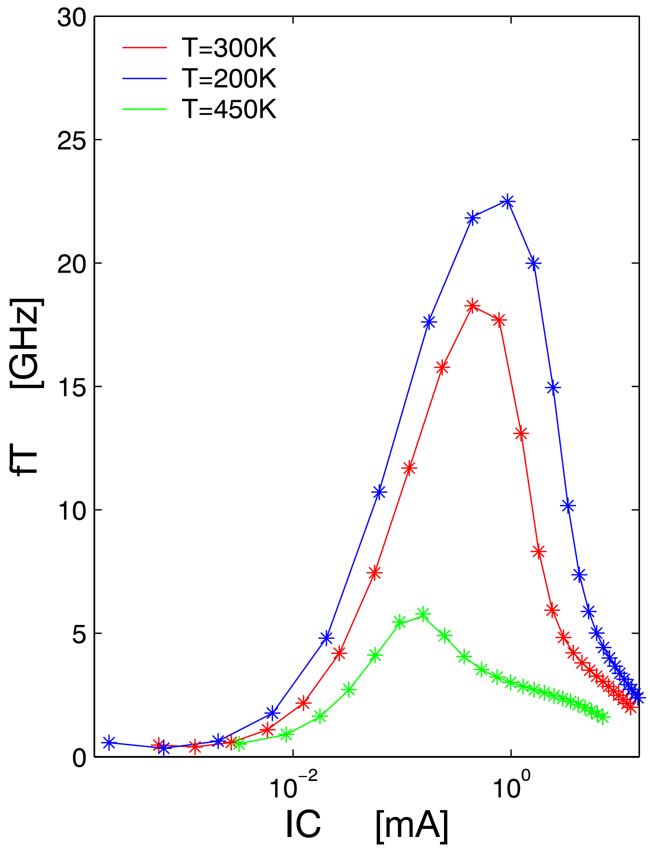


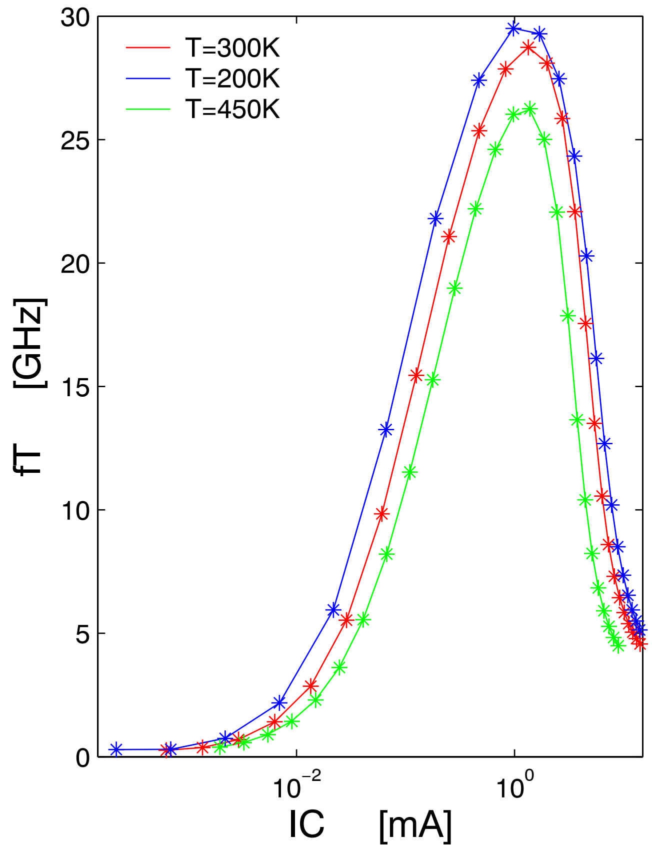


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: transit frequency (@ 0.5GHz)

VBC = 0.5V, -2.5V; Version 2.2: continuous line, Version 2.1: symbols





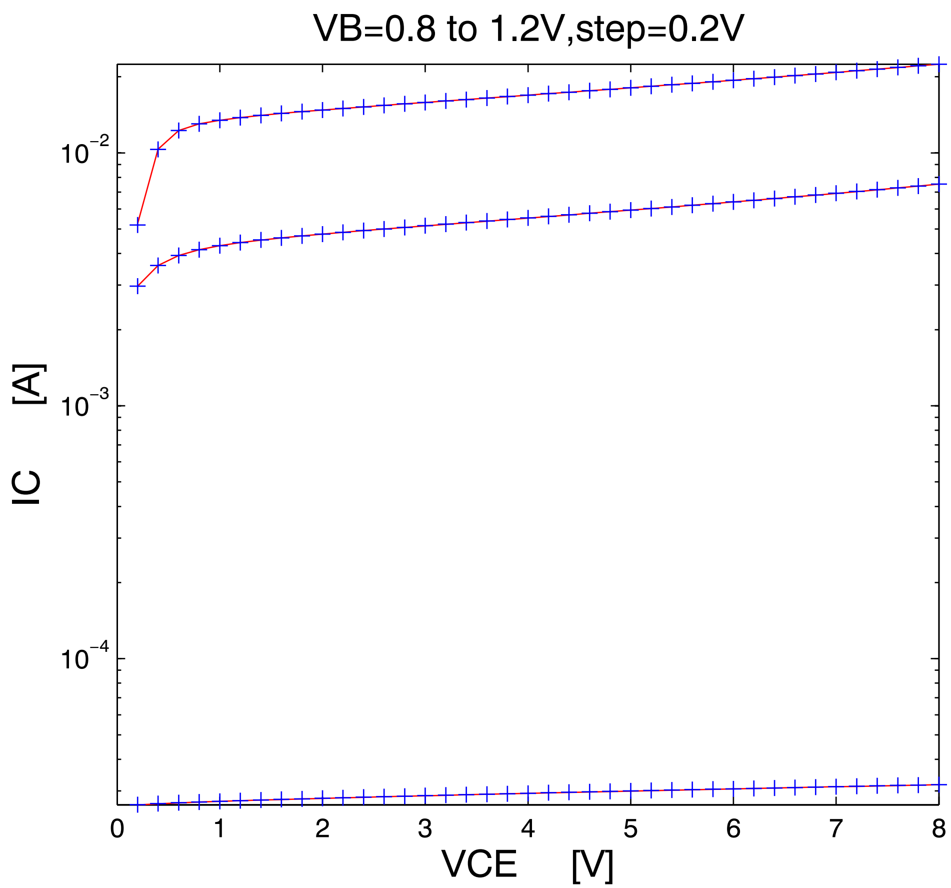
Version 2.22 vs. Version 2.1: Self-Heating Results

- v2.22 with FLSH=1 vs. v2.1
  - only IT and IAVL in SH calculation
- v2.22 with FLSH=1 vs. v2.22 with flsh=2
  - FLSH=2 considers all terms in SH calculation

Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: forced-VBE output characteristics

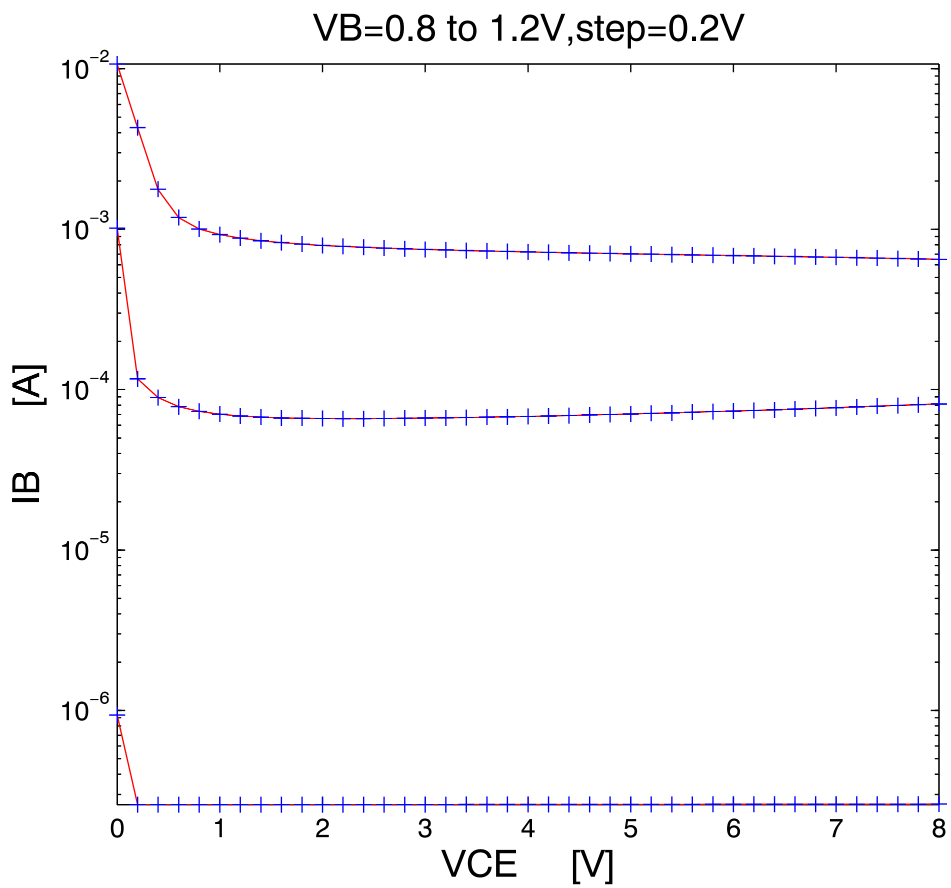
FLSH=1, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: IB-VCE characteristics

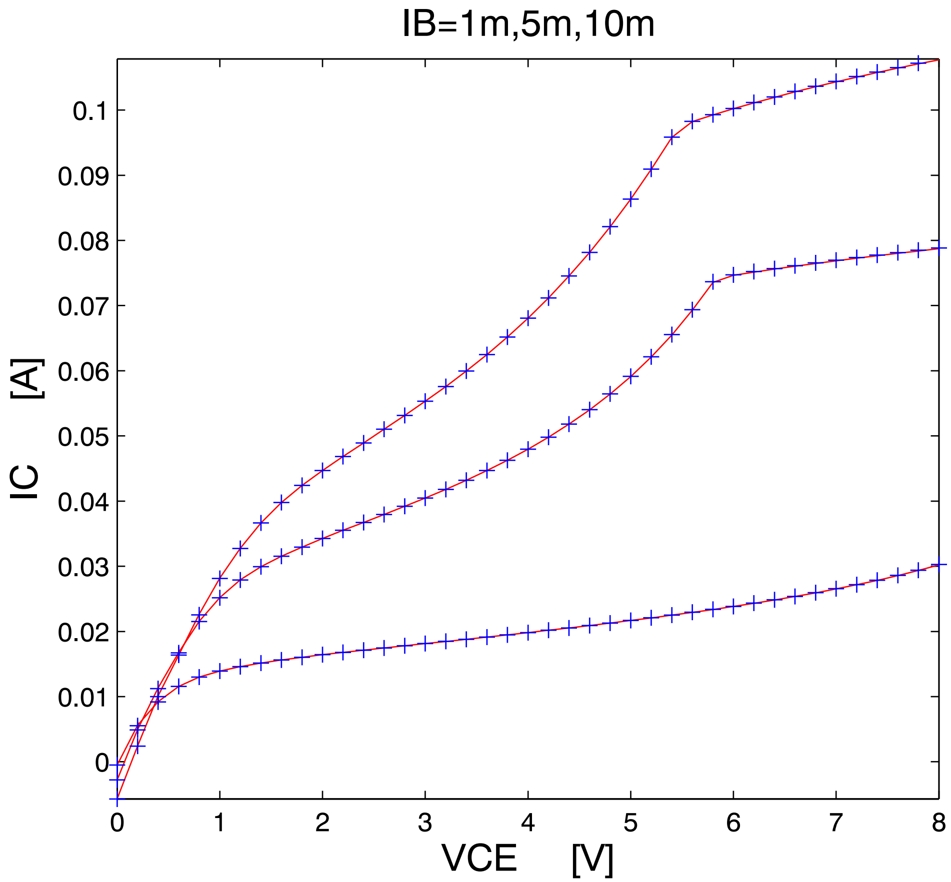
FLSH=1, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: forced-IB output characteristics

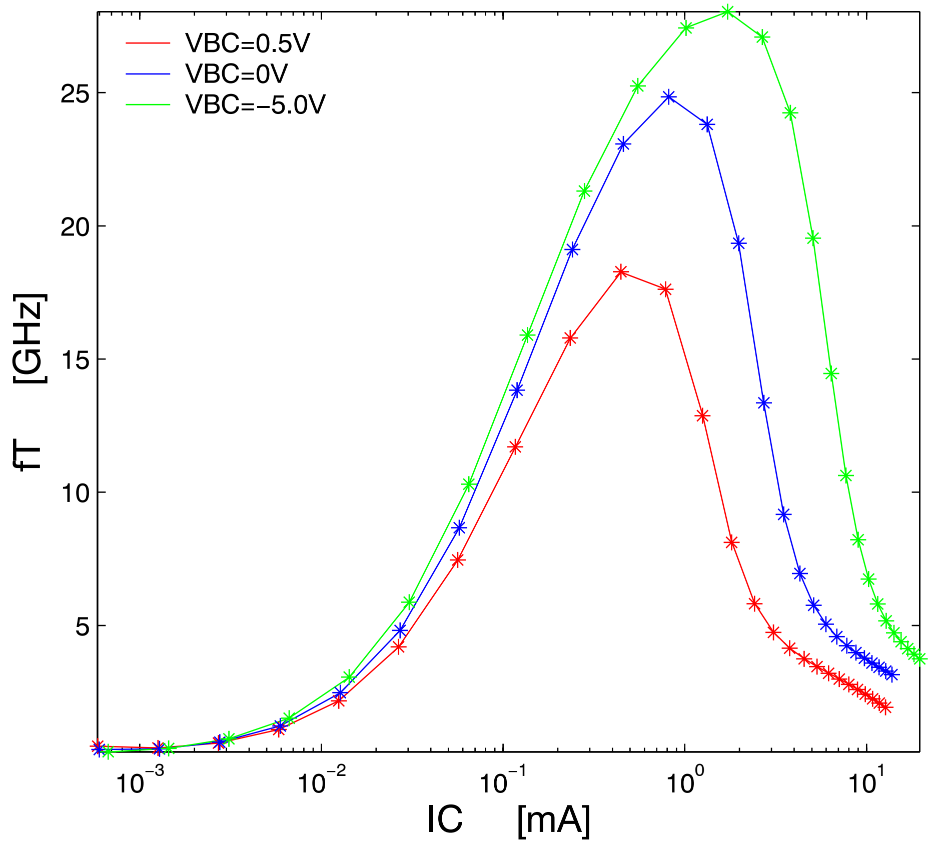
FLSH=1, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: transit frequency (@ 0.5GHz)

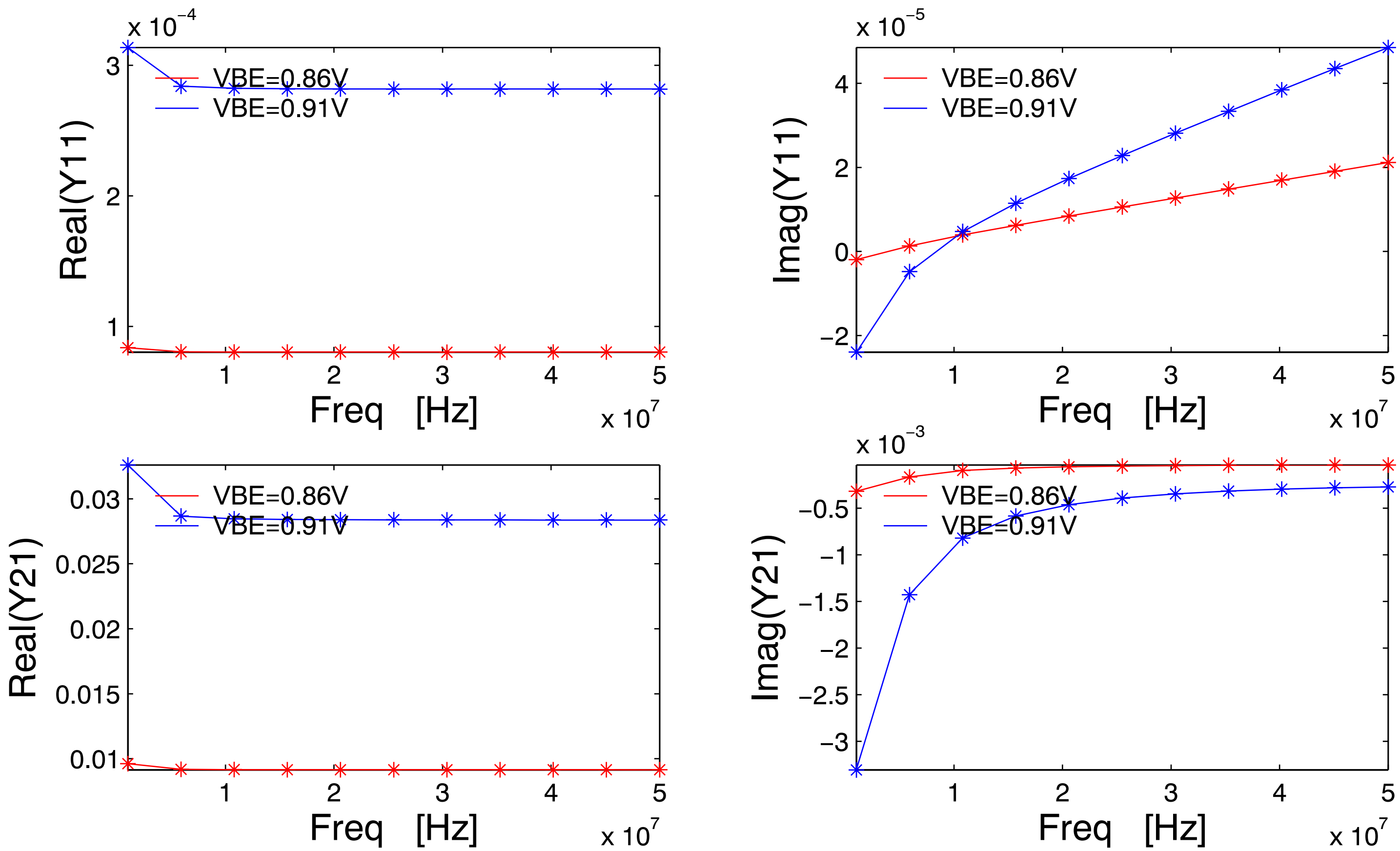
FLSH=1, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: Y11 and Y21

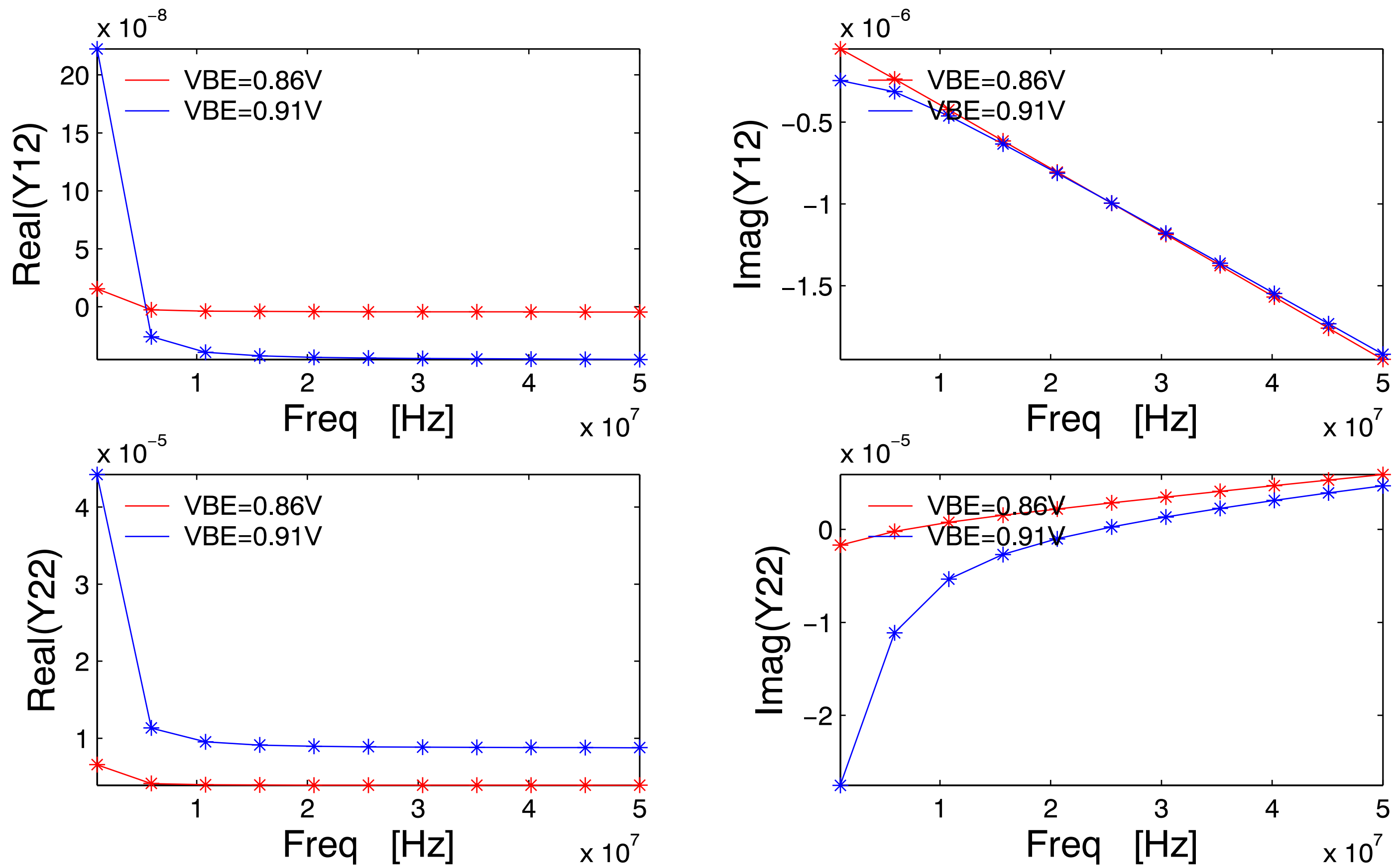
FLSH=1, VBC=-5V, Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

comparison at T = 300K: Y12 and Y22

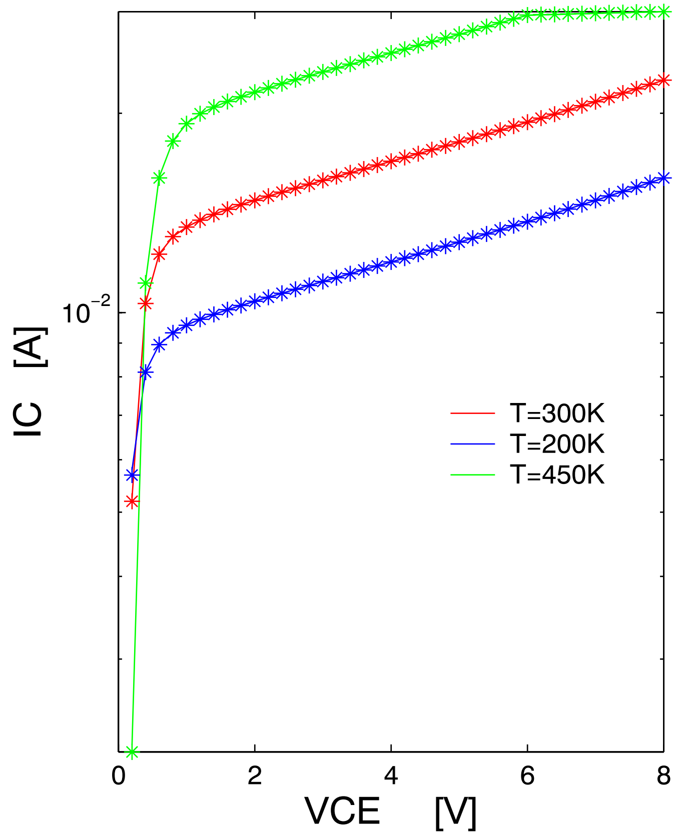
FLSH=1, VBC=-5V, Version 2.2: continuous line, Version 2.1: symbols

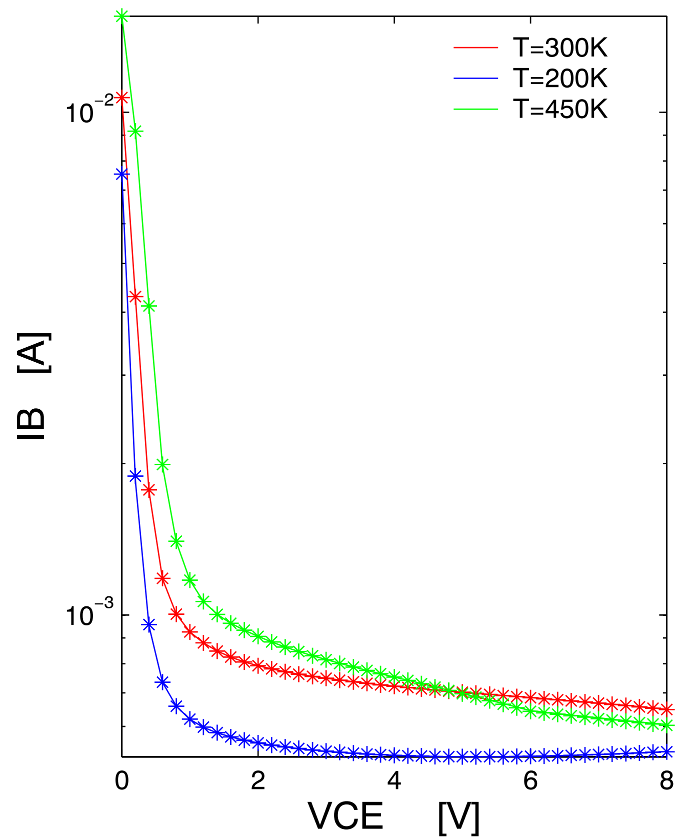


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: forced-VBE output characteristics

FLSH=1, VBE = 1.2V; Version 2.2: continuous line, Version 2.1: symbols

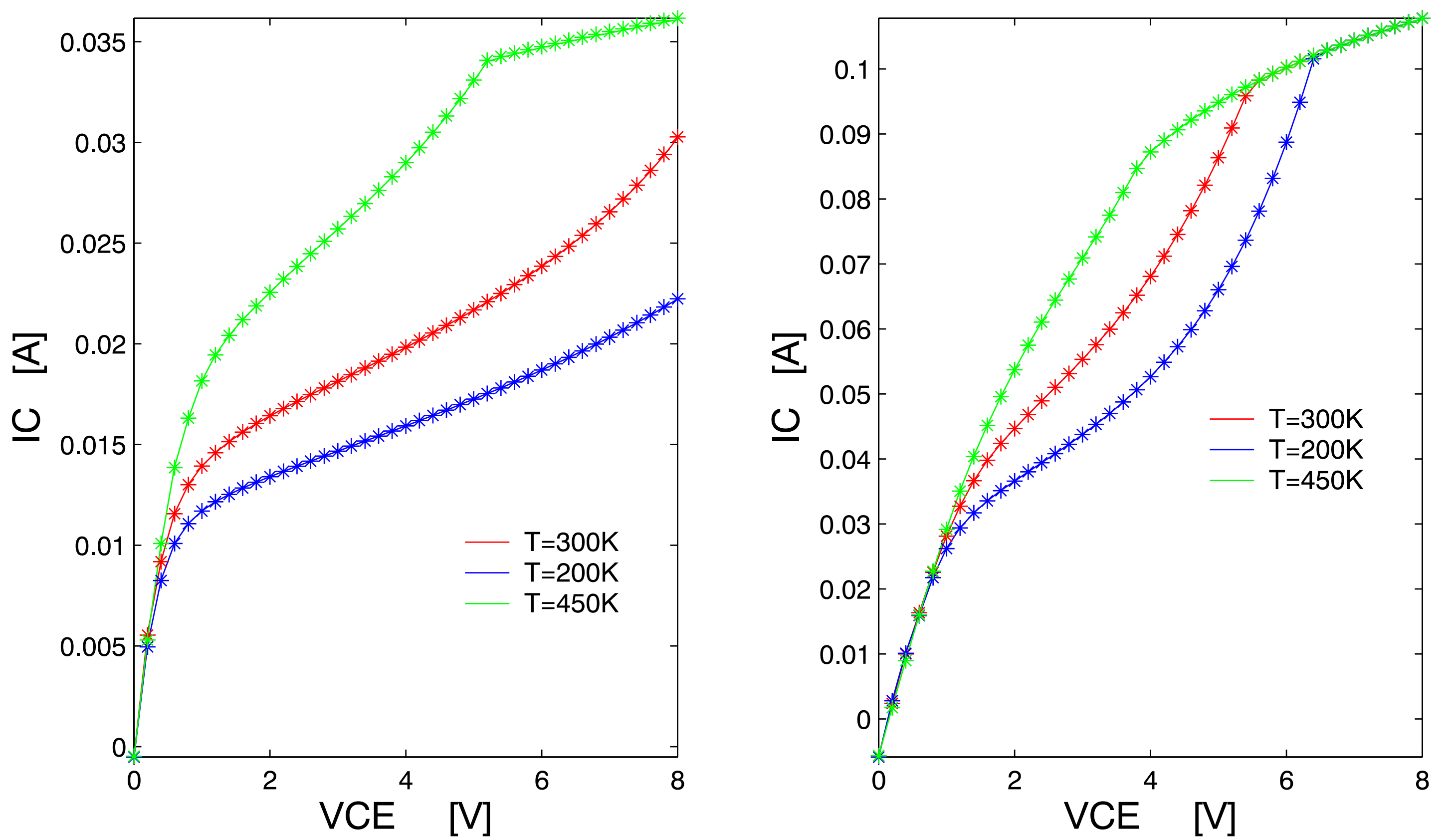




Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: forced-IB output characteristics

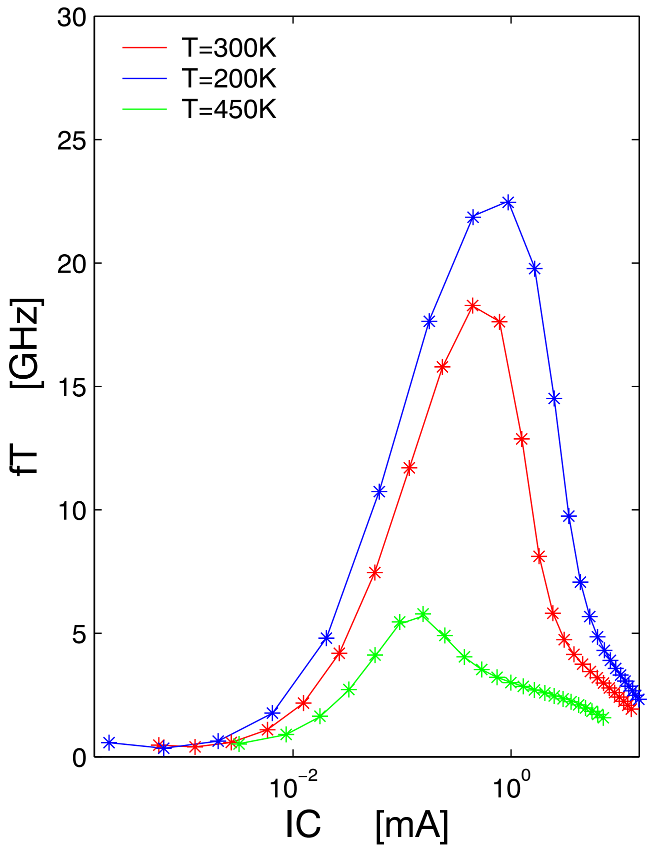
FLSH=1, IB=1mA,10mA, Version 2.2: continuous line, Version 2.1: symbols

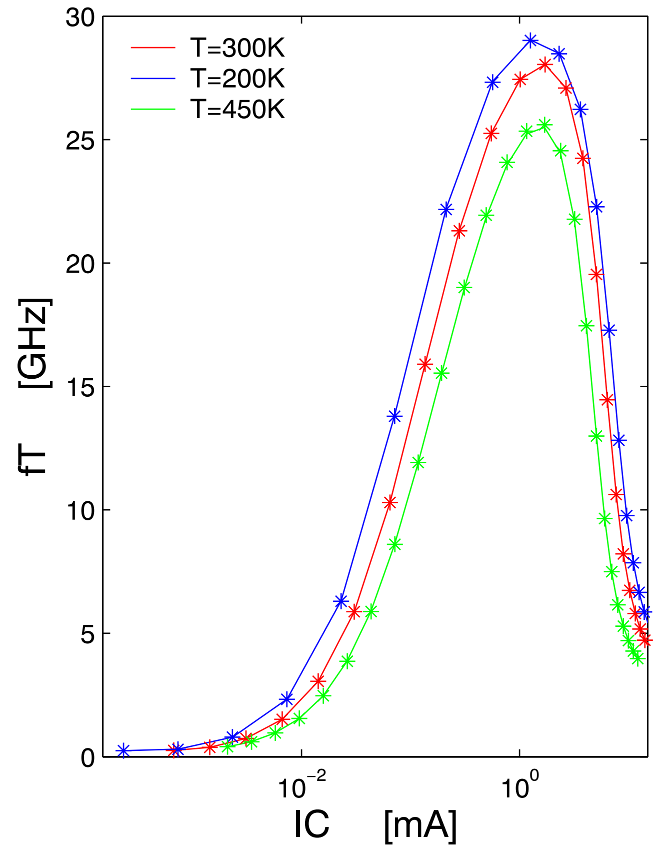


Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: transit frequency (@ 0.5GHz)

FLSH=1, VBC = 0.5V, -5V; Version 2.2: continuous line, Version 2.1: symbols

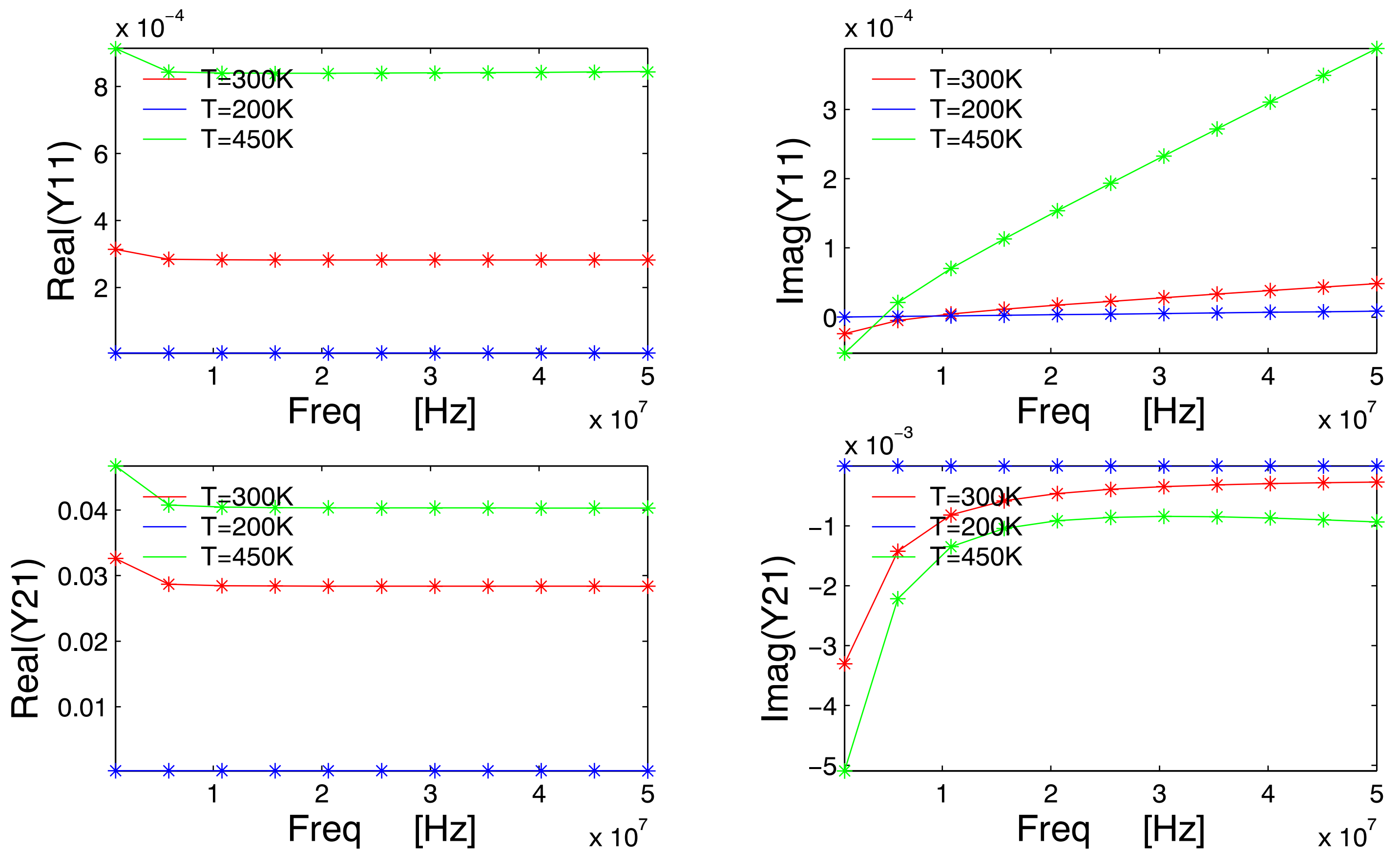




Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: Y11 and Y21

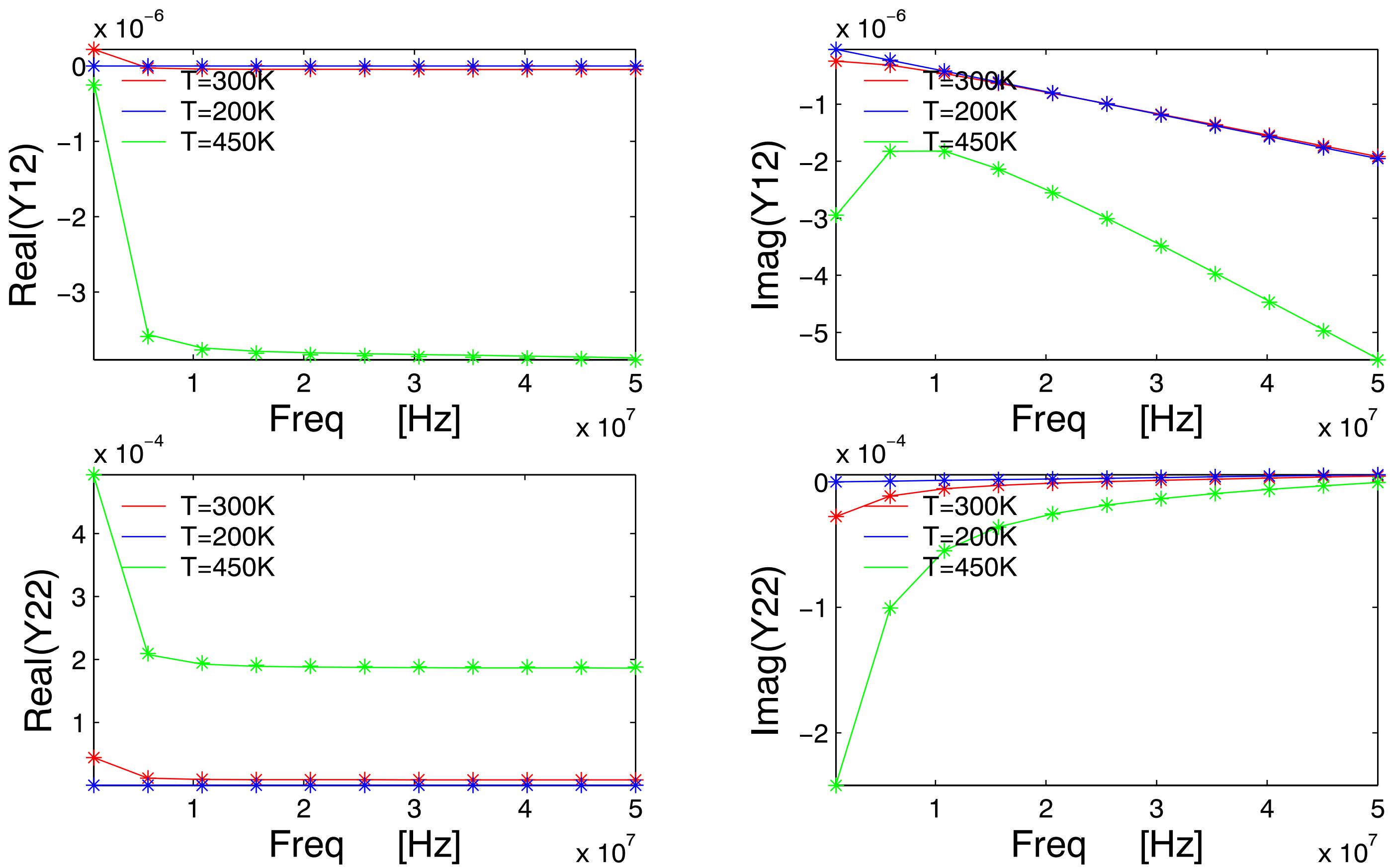
FLSH=1, VBC = -5V; Version 2.2: continuous line, Version 2.1: symbols



Version 2.22 vs. Version 2.1 (cont'd)

temperature dependence: Y12 and Y22

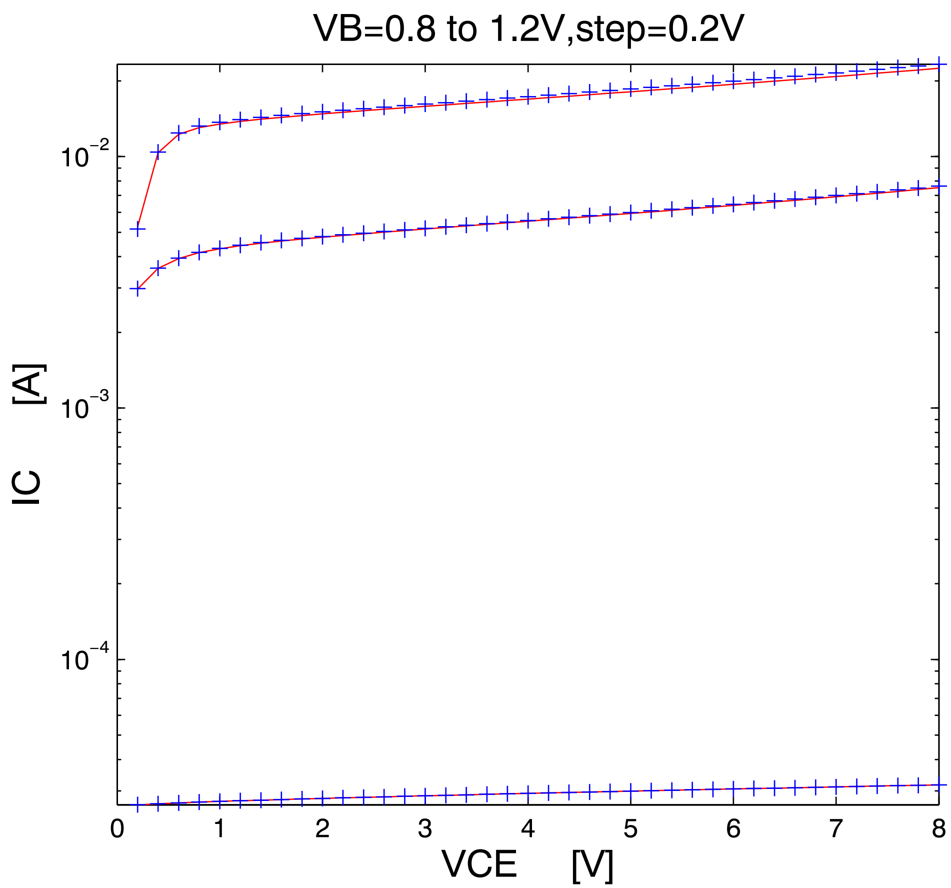
FLSH=1, VBC = -5V; Version 2.2: continuous line, Version 2.1: symbols



Version 2.22: FLSH=1 vs. FLSH=2

comparison at T = 300K: forced-VBE output characteristics

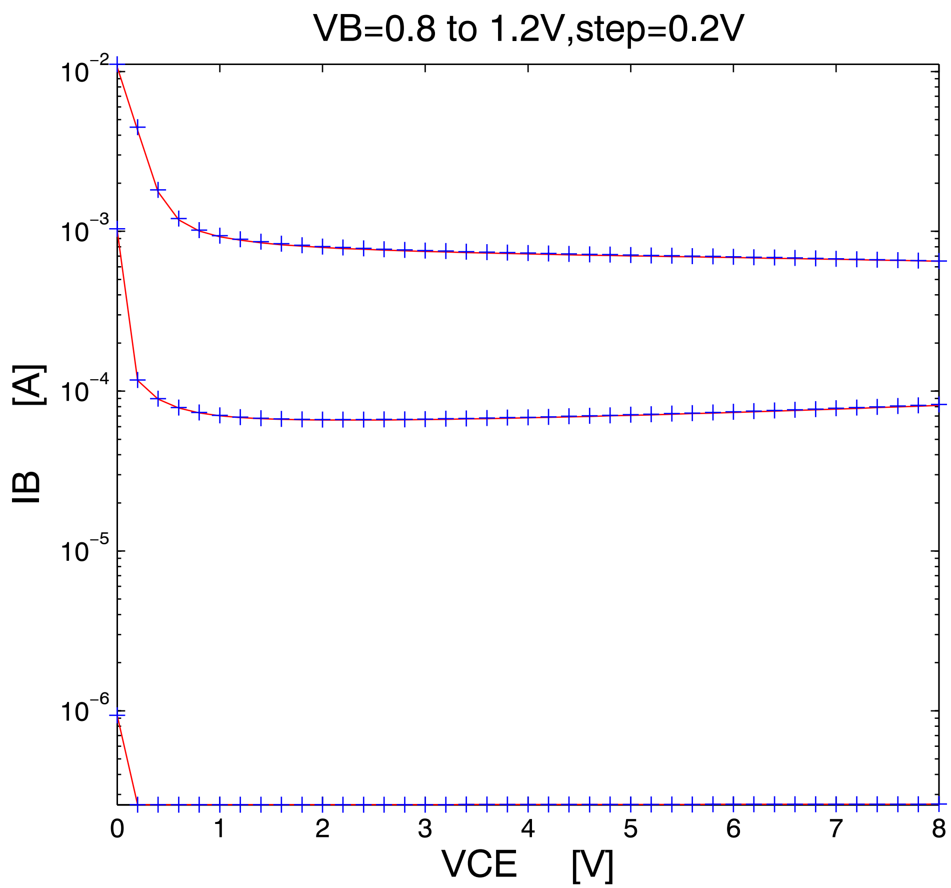
FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

comparison at T = 300K: IB-VCE characteristics

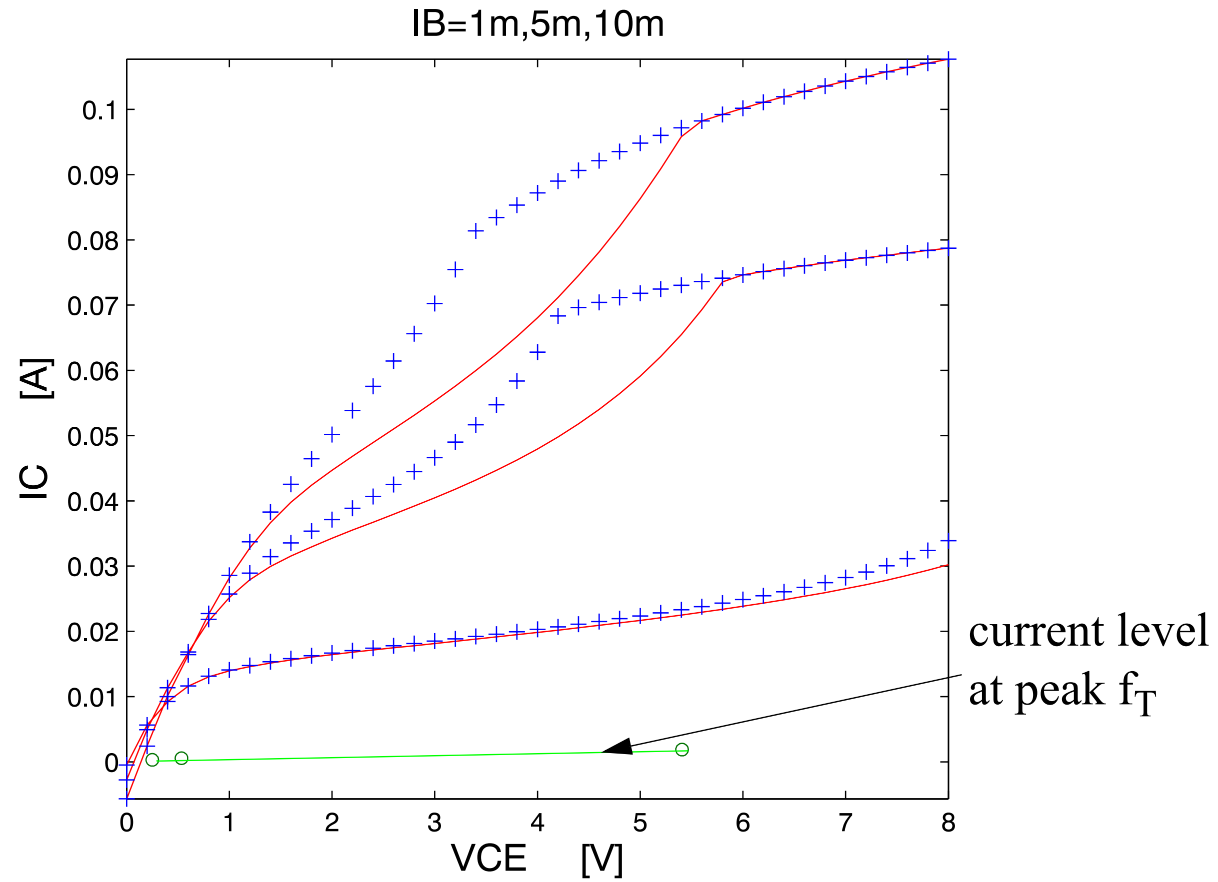
FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

comparison at T = 300K: forced-IB output characteristics

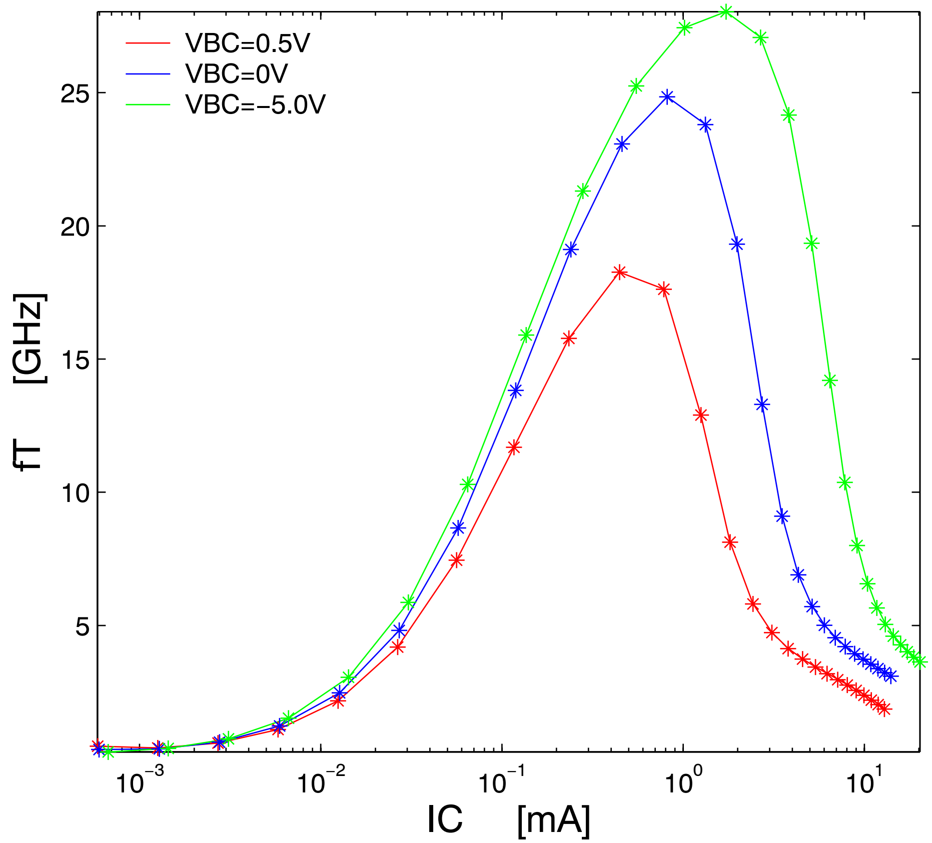
FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

comparison at T = 300K: transit frequency (@ 0.5GHz)

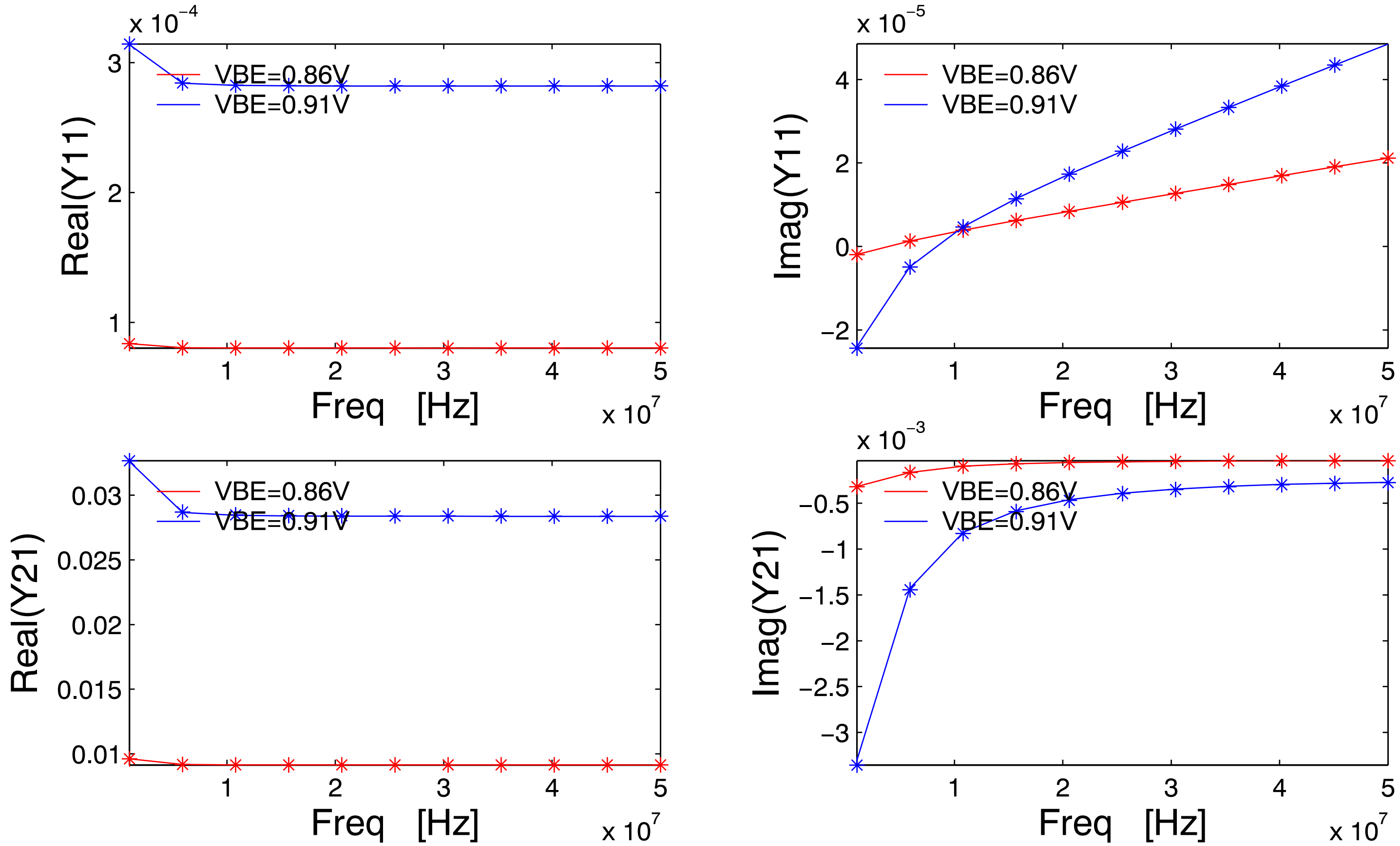
FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

comparison at T = 300K: Y11 and Y21

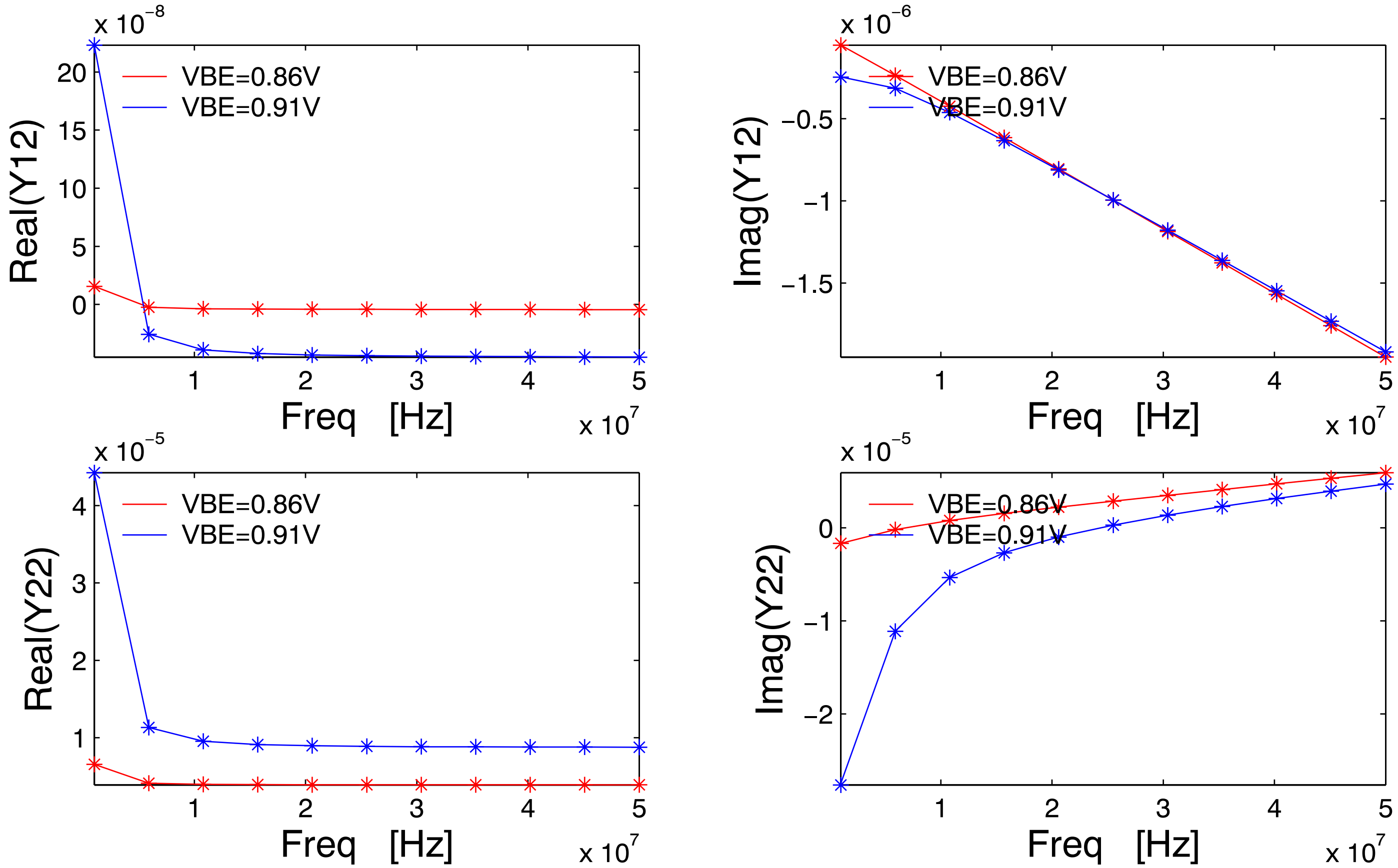
VBC=-5V, FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

comparison at T = 300K: Y12 and Y22

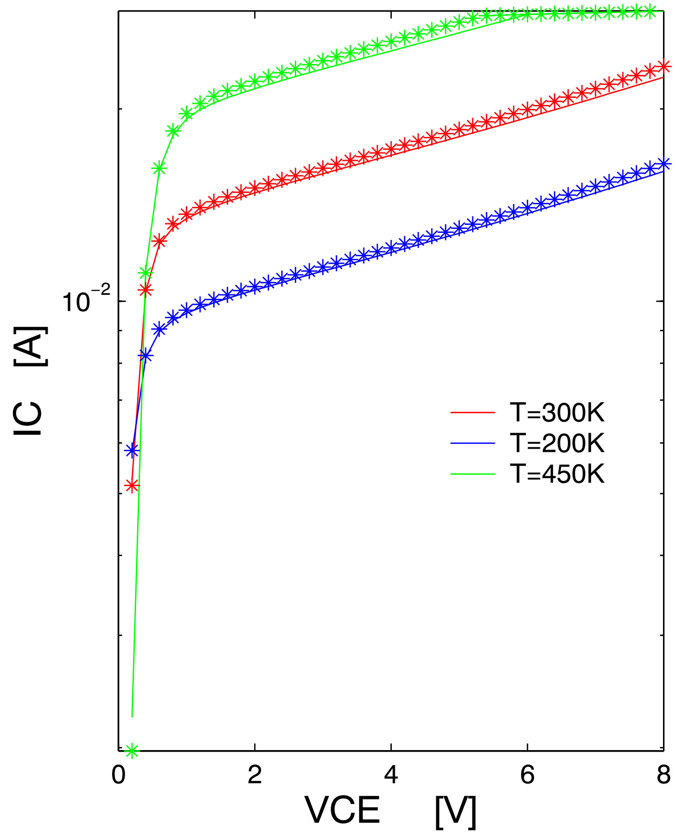
VBC=-5V, FLSH=1: continuous line, FLSH=2: symbols

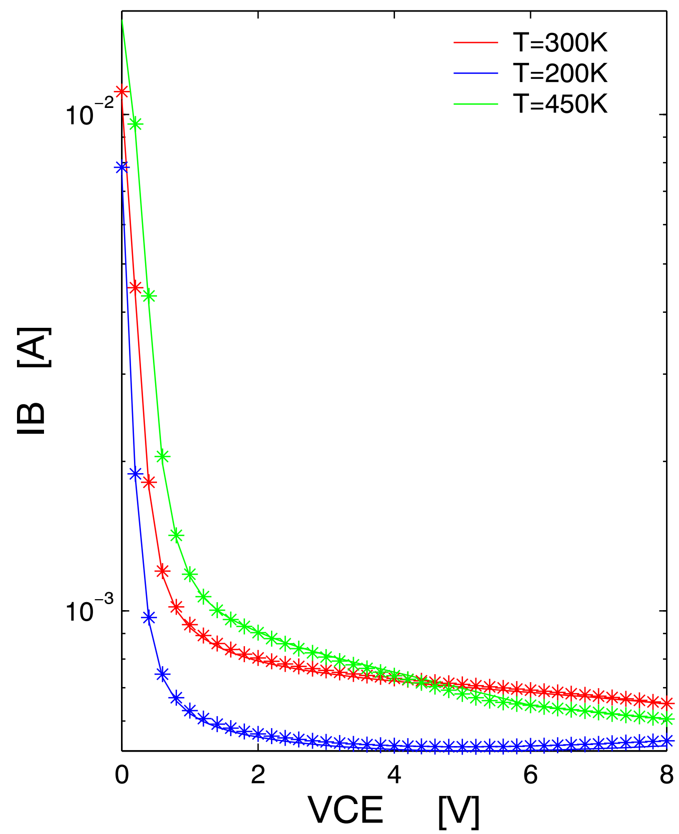


Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

temperature dependence: forced-VBE output characteristics

VBE = 1.2V; FLSH=1: continuous line, FLSH=2: symbols

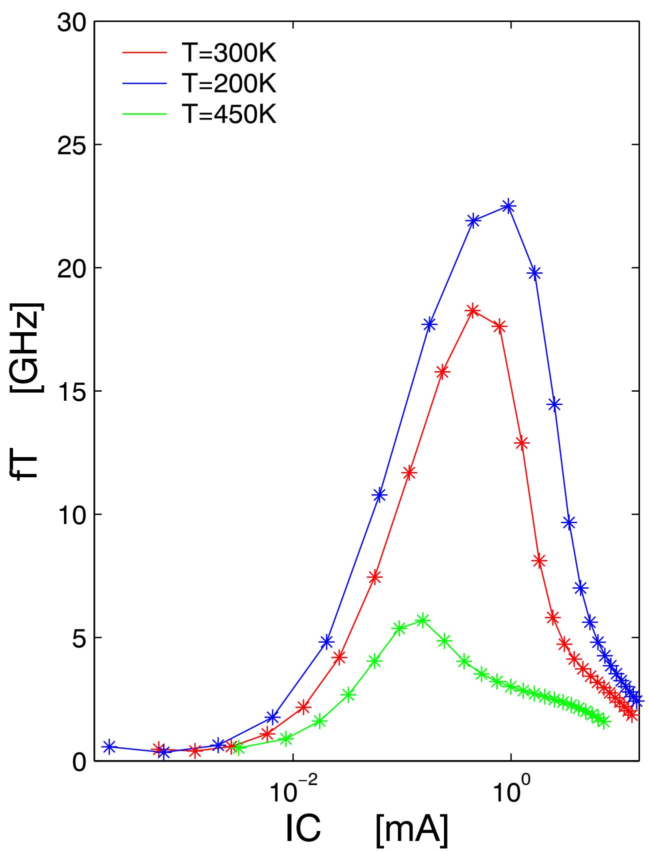


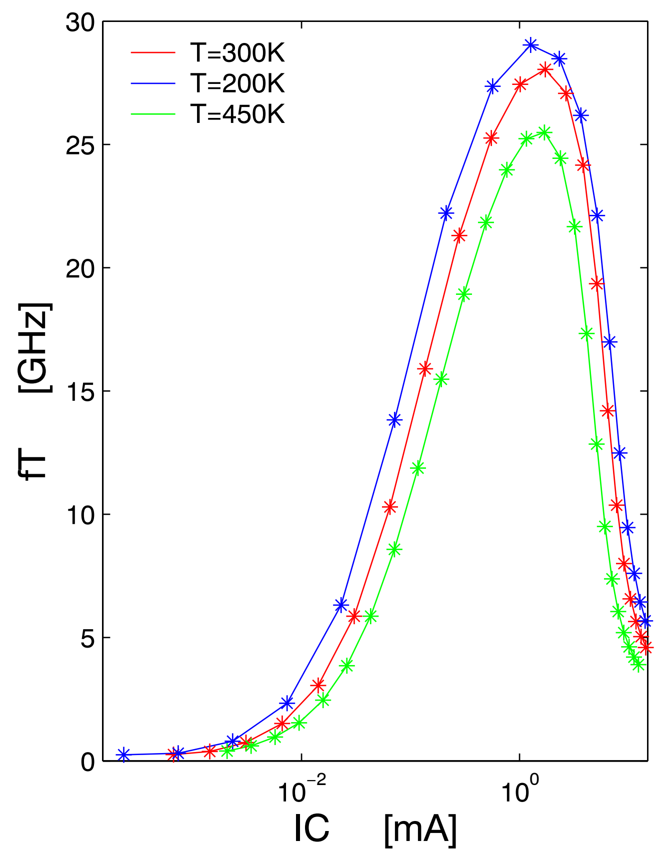


Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

temperature dependence: transit frequency (@ 0.5GHz)

VBC = 0.5V, -5V; FLSH=1: continuous line, FLSH=2: symbols

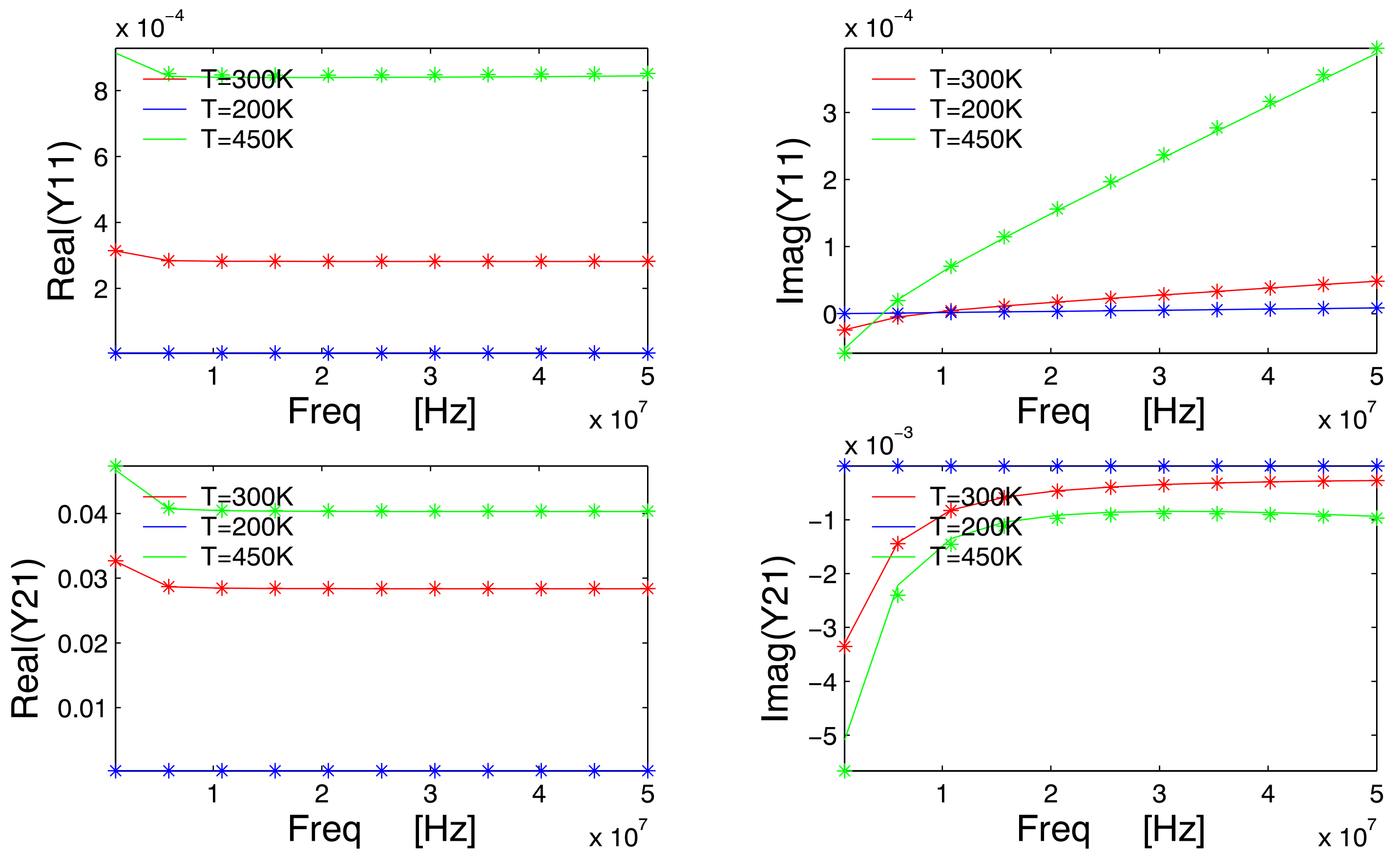




Version 2.22: FLSH=1 vs. FLSH=2 (cont'd)

temperature dependence: Y11 and Y21

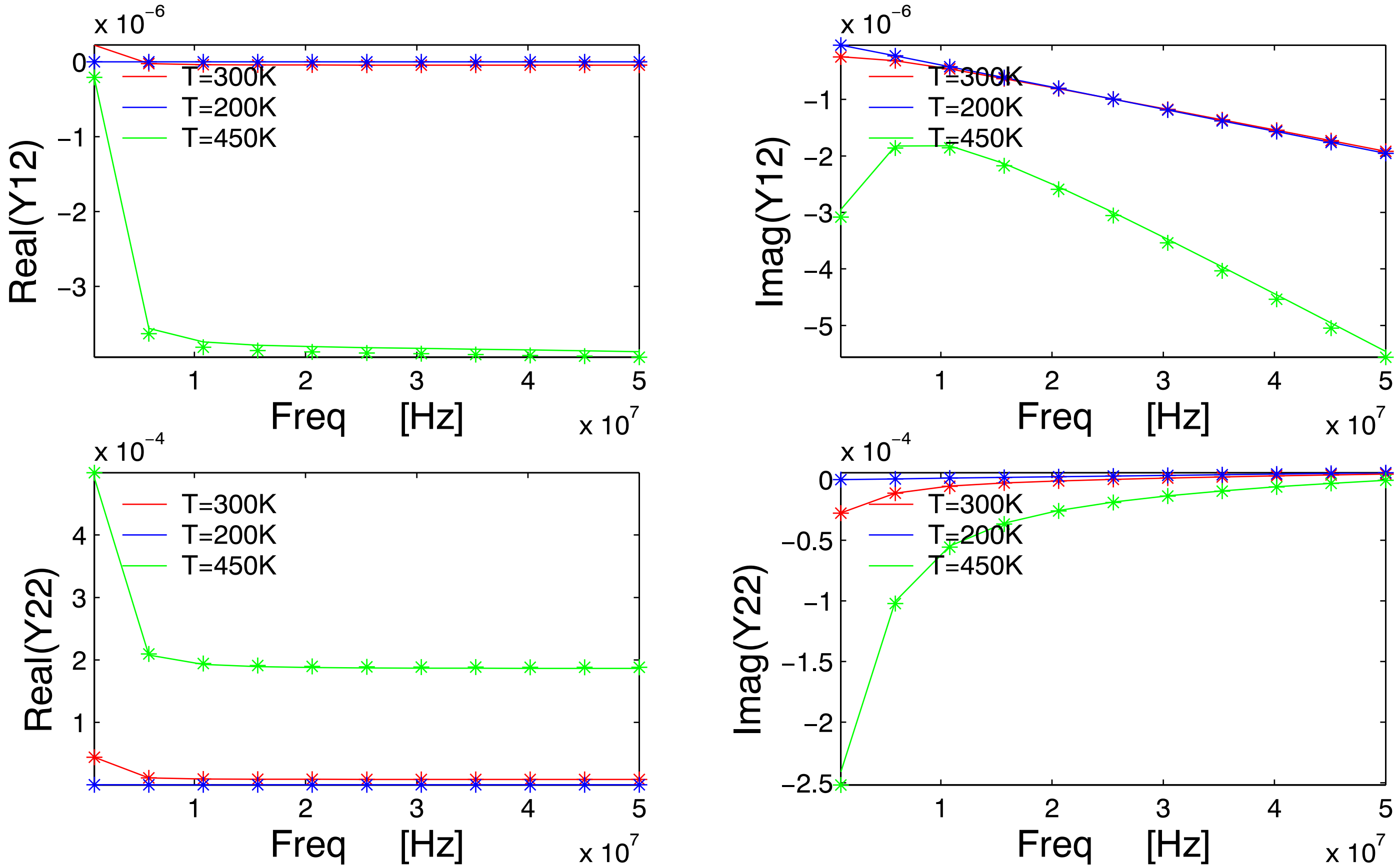
VBC = -5V; FLSH=1: continuous line, FLSH=2: symbols



Version 2.22: FLSH=1 vs. FLSH=2 (cont’d)

temperature dependence: Y12 and Y22

VBC = -5V; FLSH=1: continuous line, FLSH=2: symbols



Conclusions

- Version 2.2 and Version 2.1 are completely equivalent
  - normal temperature over bias
  - themperature variation: 200K to 450K
  - with and without Self-Heating

Other activities

- Documentation
  - Release notes available on new web-site
  - updated full documentation for v2.2 has been available since Nov. ’05
  - for application related information: visit HICUM Workshop website

- more code/implementation related investigations
  - efficient way for implementing NQS effects
  - correlated noise between base and collector current : BCTM 2006
  - Verilog-AMS specific code improvements
  - model compiler related information exchange (Freescale, Tiburon)

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